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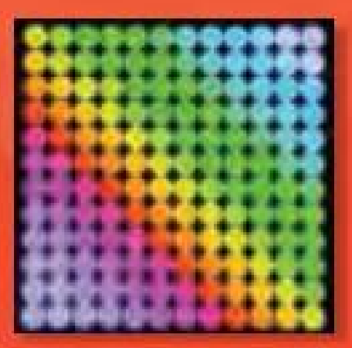

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Practical
Electronics

Volume 50. No. 4
April 2021
ISSN 2632 573X

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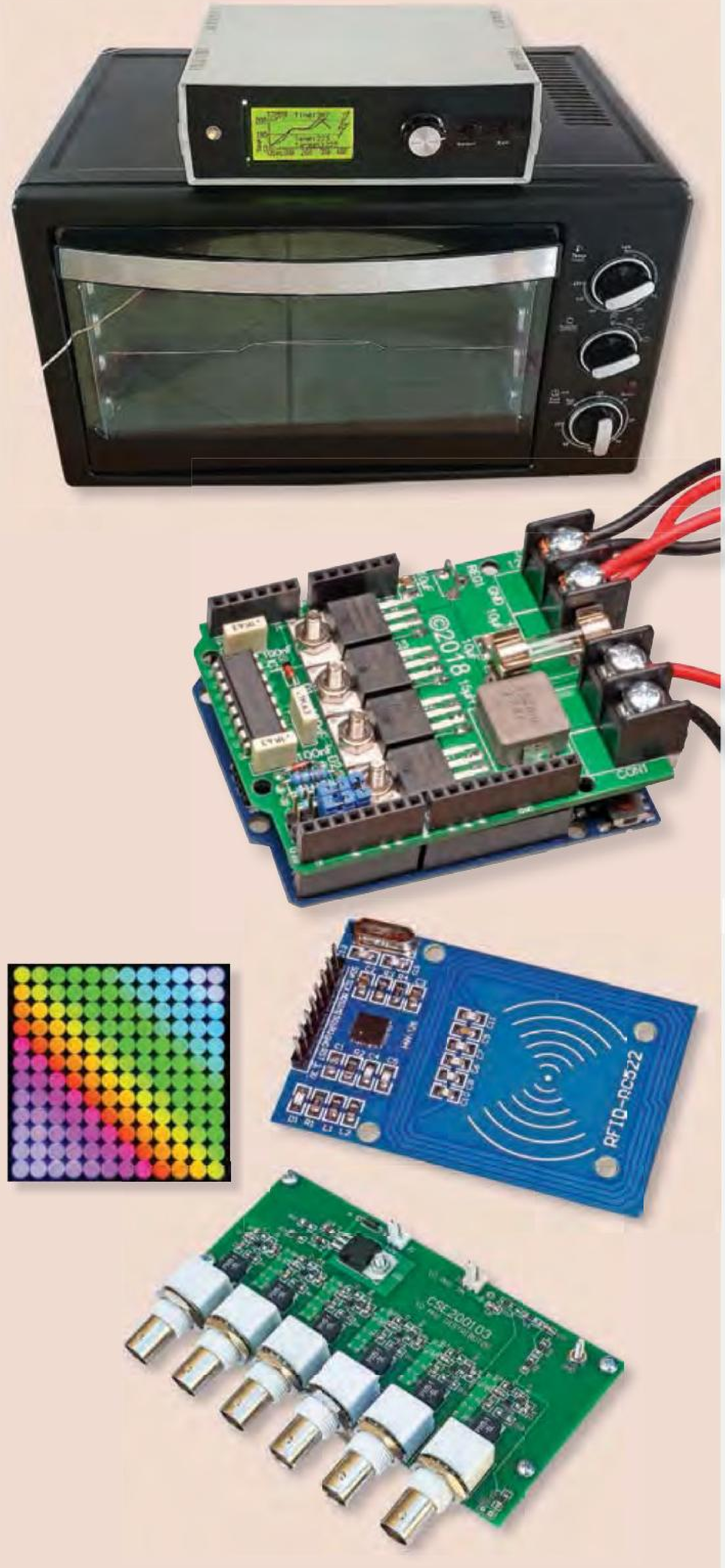

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The May 2021 issue of *Practical Electronics* will be published on Thursday, 8 April 2021 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

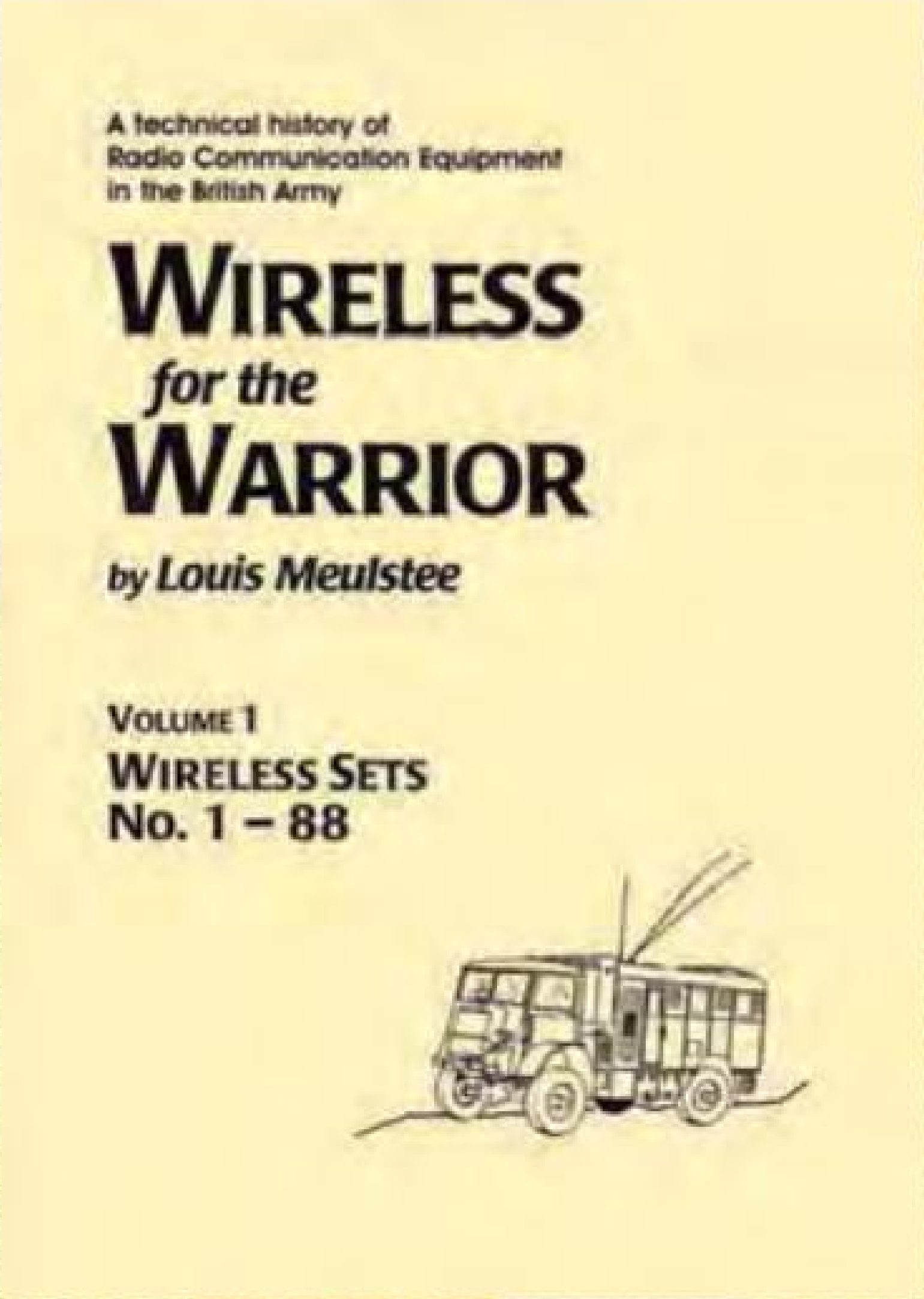
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



A technical history of Radio Communication Equipment in the British Army

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by Louis Meulstee

VOLUME 1

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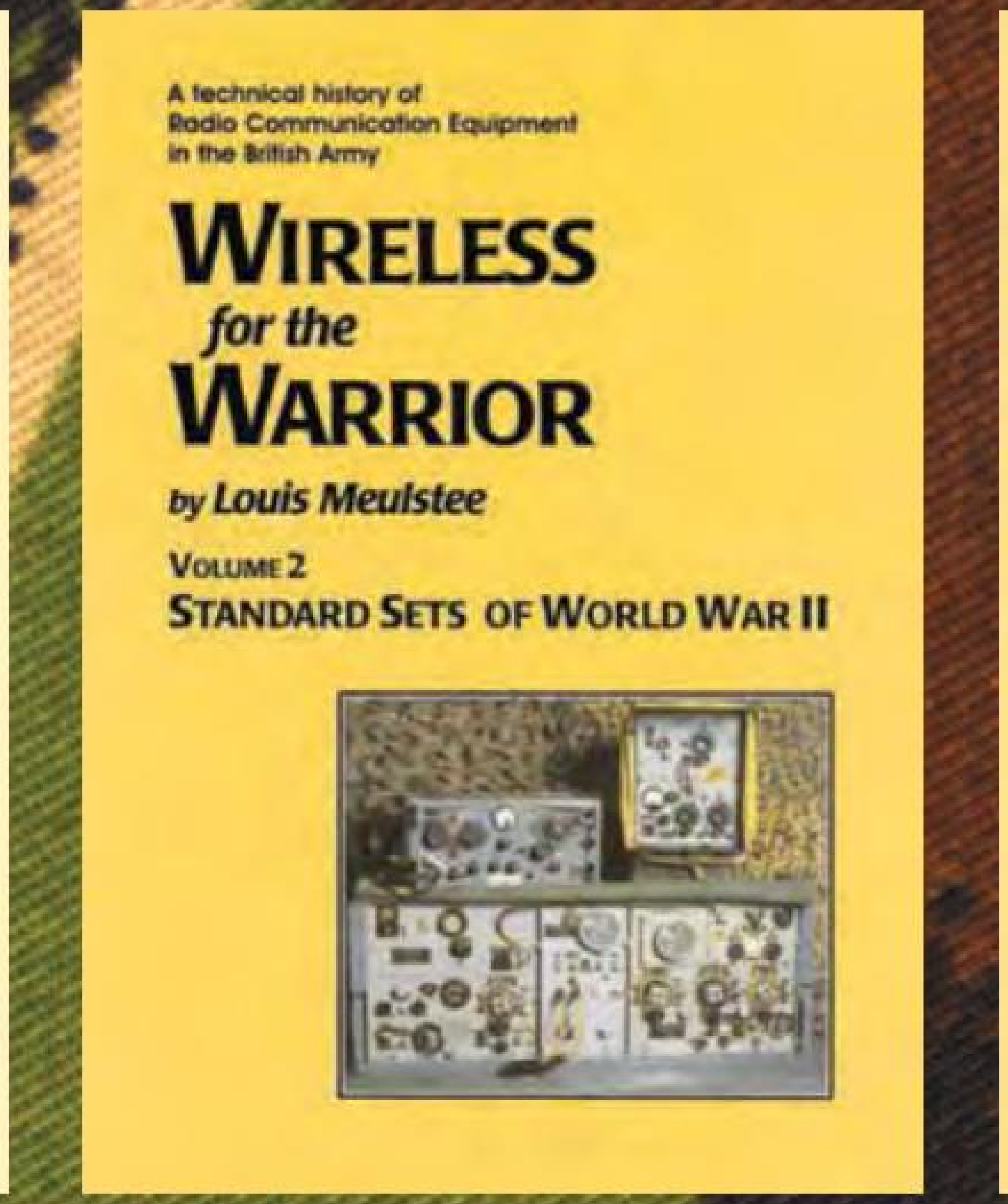

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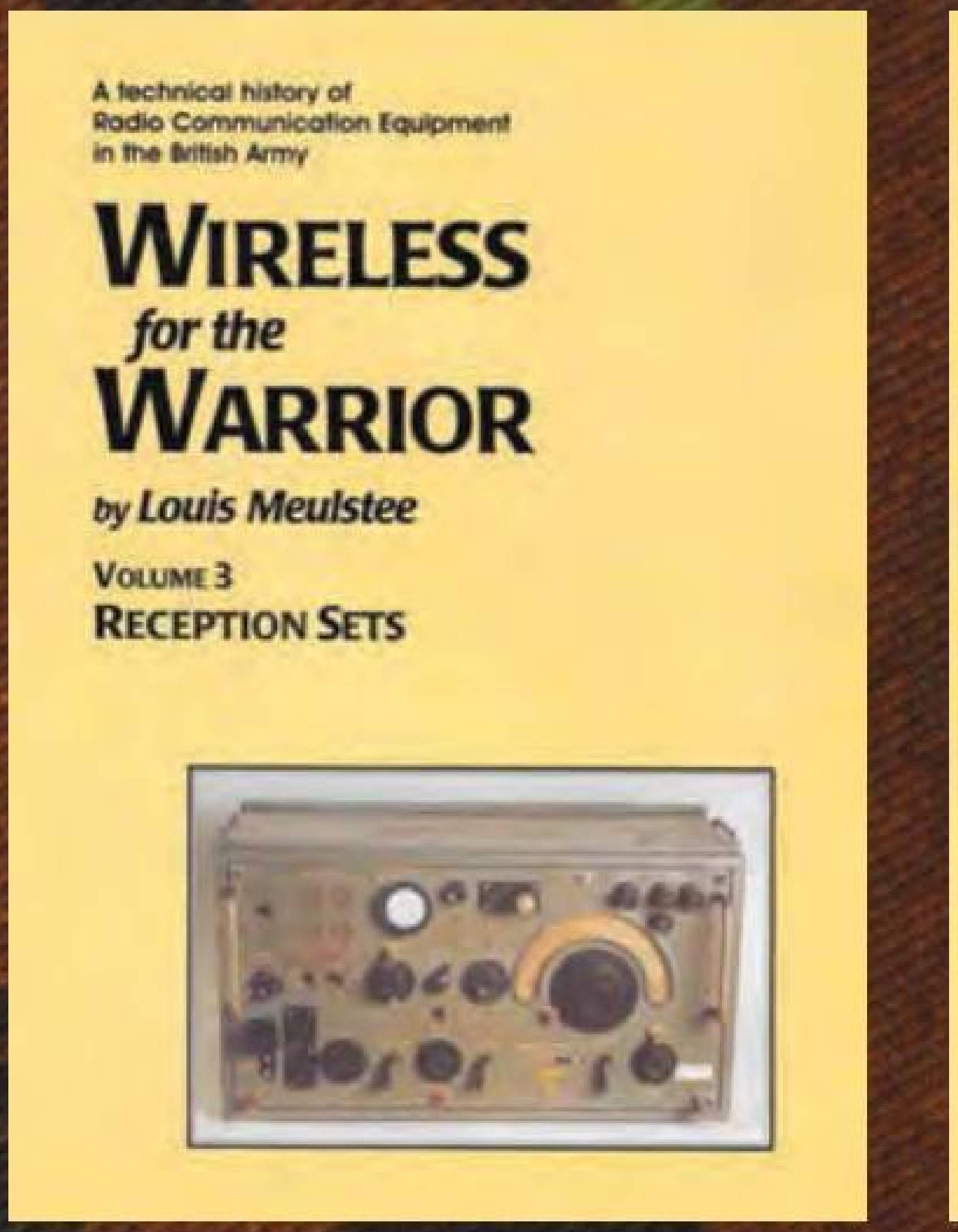

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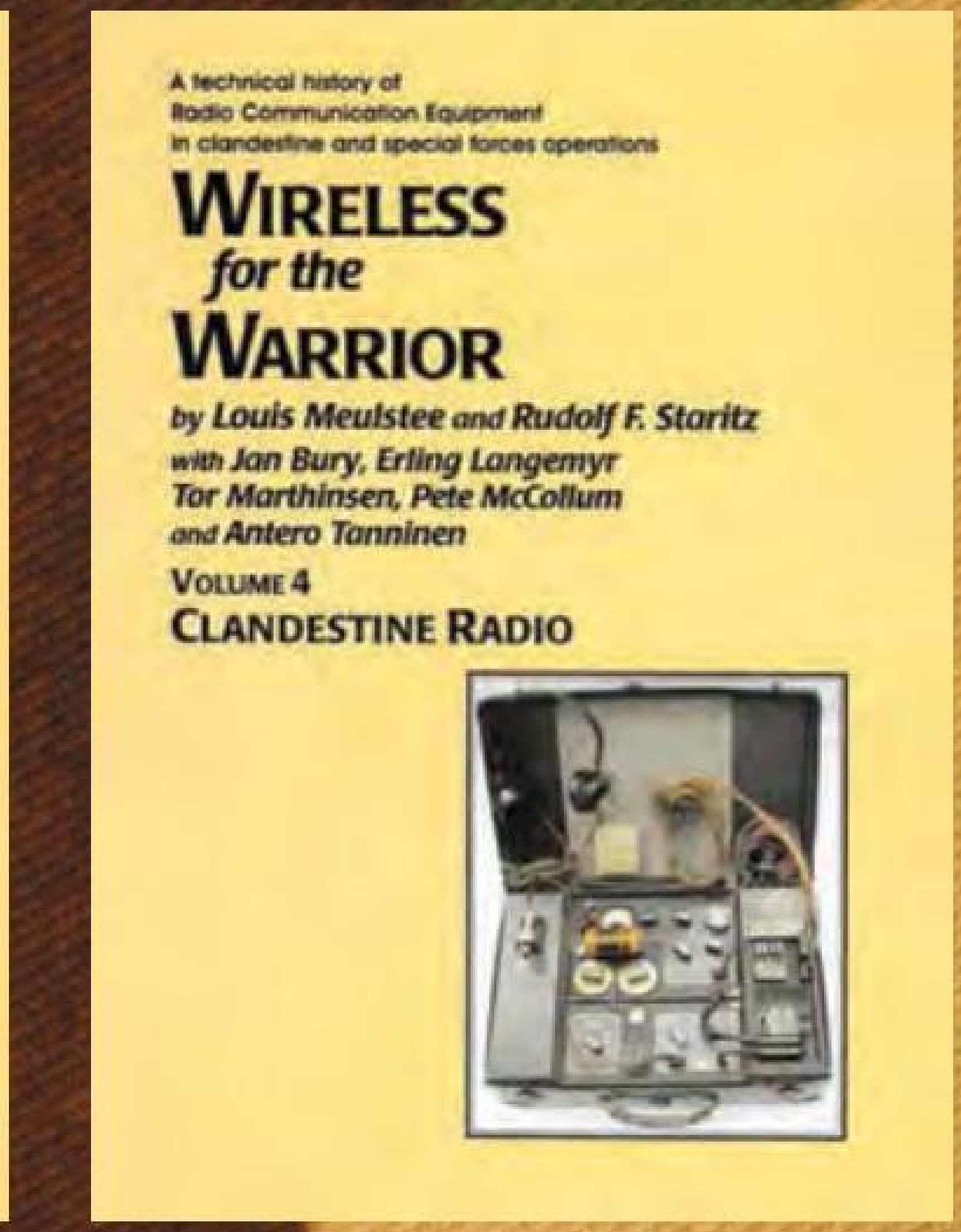

A technical history of Radio Communication Equipment in clandestine and special forces operations

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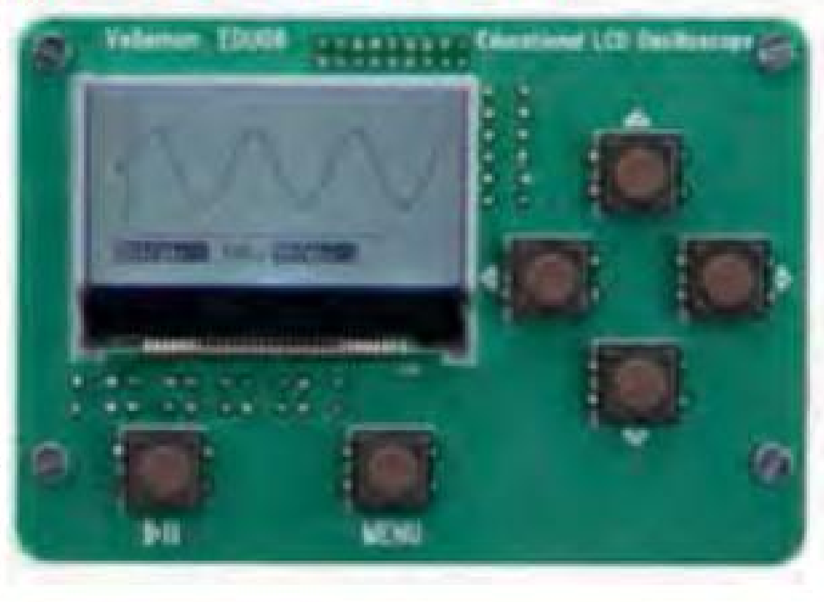
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Volume 50. No. 4
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PE readers are a diverse bunch!

If they like something they are generous with their praise, but if not, then they aren't shy about, shall we say, suggesting improvements. That's a good thing, but I can't help feeling sometimes that you can please some of the people some of the time… well, you know how this continues.

Probably the most long-lived fault line dividing readers into two often-irreconcilable camps is analogue versus digital. On the one hand, I receive emails and letters from the digital tribe, wanting to know when we will cover FPGAs, a new PIC or wanting information on a recent microcontroller upgrade. They tend to be not very interested in Hi-Fi amplifiers, op amps or indeed anything that doesn't run strictly at 3.3/5V. On the other hand, there are adherents to the analogue cause, who tend to view digital electronics as some kind of jumped-up Lego. They also like to point out that digital is really only a special case of analogue. Some of them would really rather we didn't use PCBs and I suspect the truly diehard members of this tribe view ICs or possibly even transistors as the start of a hobby-destroying rot that is ruining 'real' electronics – bring back valves (tubes) they undoubtedly mutter under their breath.

The answer to all of the above is of course, 'yes' and 'no'. Yes, we appreciate your comments and your commitment to your area of electronics, and 'no' we can't ignore the 'other side'. The beauty, elegance and fun of electronics is that it really is a broad church. From point-to-point-wired triode-based headphone amplifiers to 32-bit-PIC digital controller projects there is room for everyone. Perhaps more to the point, we need all our readers, and if we started to ignore and lose a big chunk of subscribers then I doubt we'd last very long. We do try very hard to find something for everyone, and while it sometimes takes a little while to cover a particular niche interest, usually we do get there.

This month

And that brings me to this month, which in typical *PE* fashion really does straddle a huge range of technologies, techniques and ideas. We have the concluding part of Jake Rothman's wonderful resurrection of the Ladybird Books *Transistor Radio* – complete with germanium PNP transistors and what can only be called *real* breadboard construction techniques! Plus, we have a really clever digital PID controller to enable you to convert a cheap electric oven into a sophisticated PCB solder reflow machine.

That's just a snapshot of all the great content lined up in this issue. We hope – whatever your preferences – you'll find something to inspire you to pick up your soldering iron.

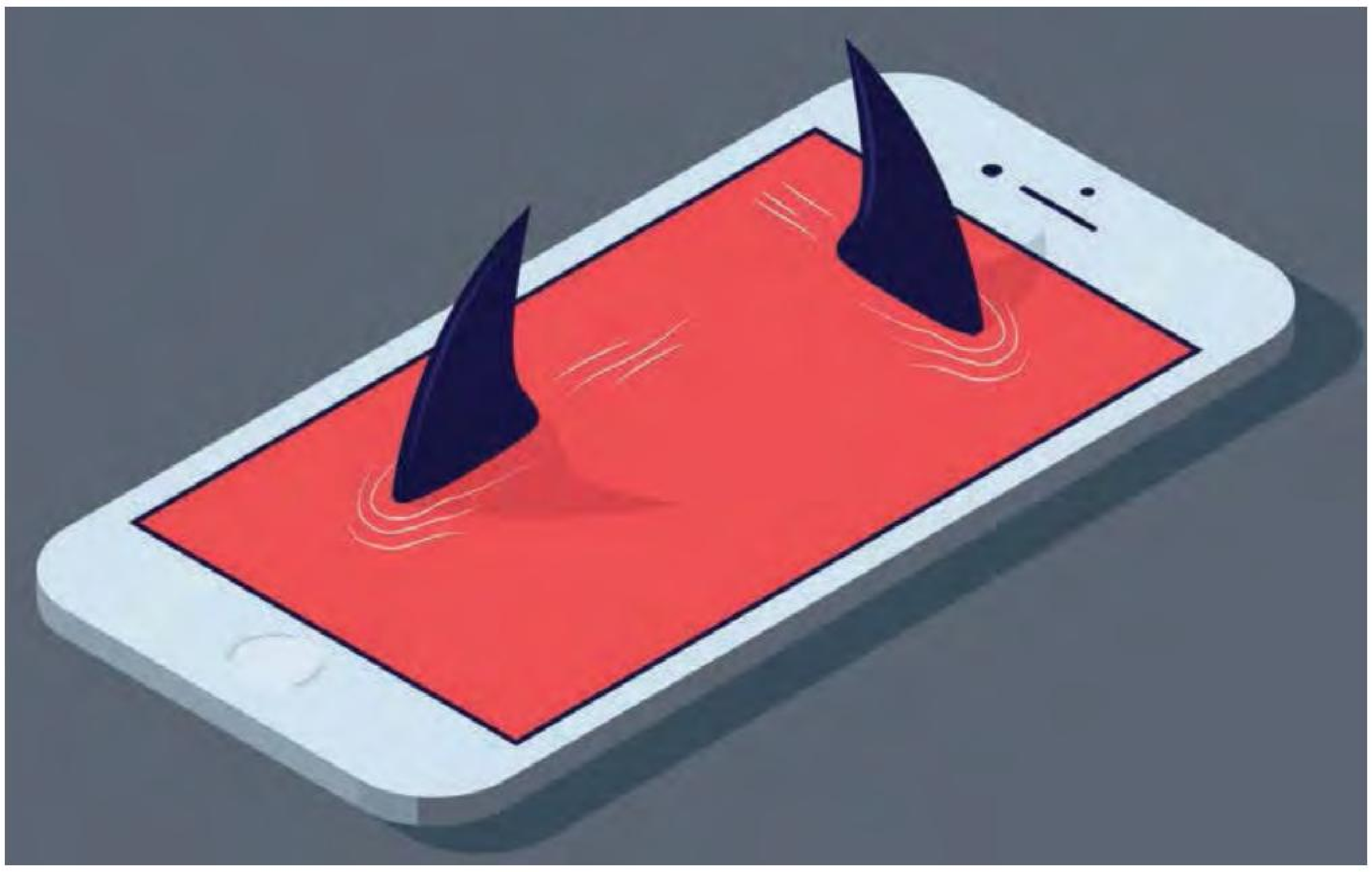
Keep well everyone

Matt Pulzer
Publisher

The Fox Report

Barry Fox's technology column

Do something useful today



Every day, we hear how the lockdown has become boom-time for scammers, because more people are at home to answer cold calls and more people with near-zero technical skills are using computers to buy, pay, work and learn on line.

Most people are now wary of giving out passwords or banking details, but they are not yet alert to the growing and potentially most costly scam – inadvertently handing access to your phone or computer or tablet to a third party.

Help your family and friends

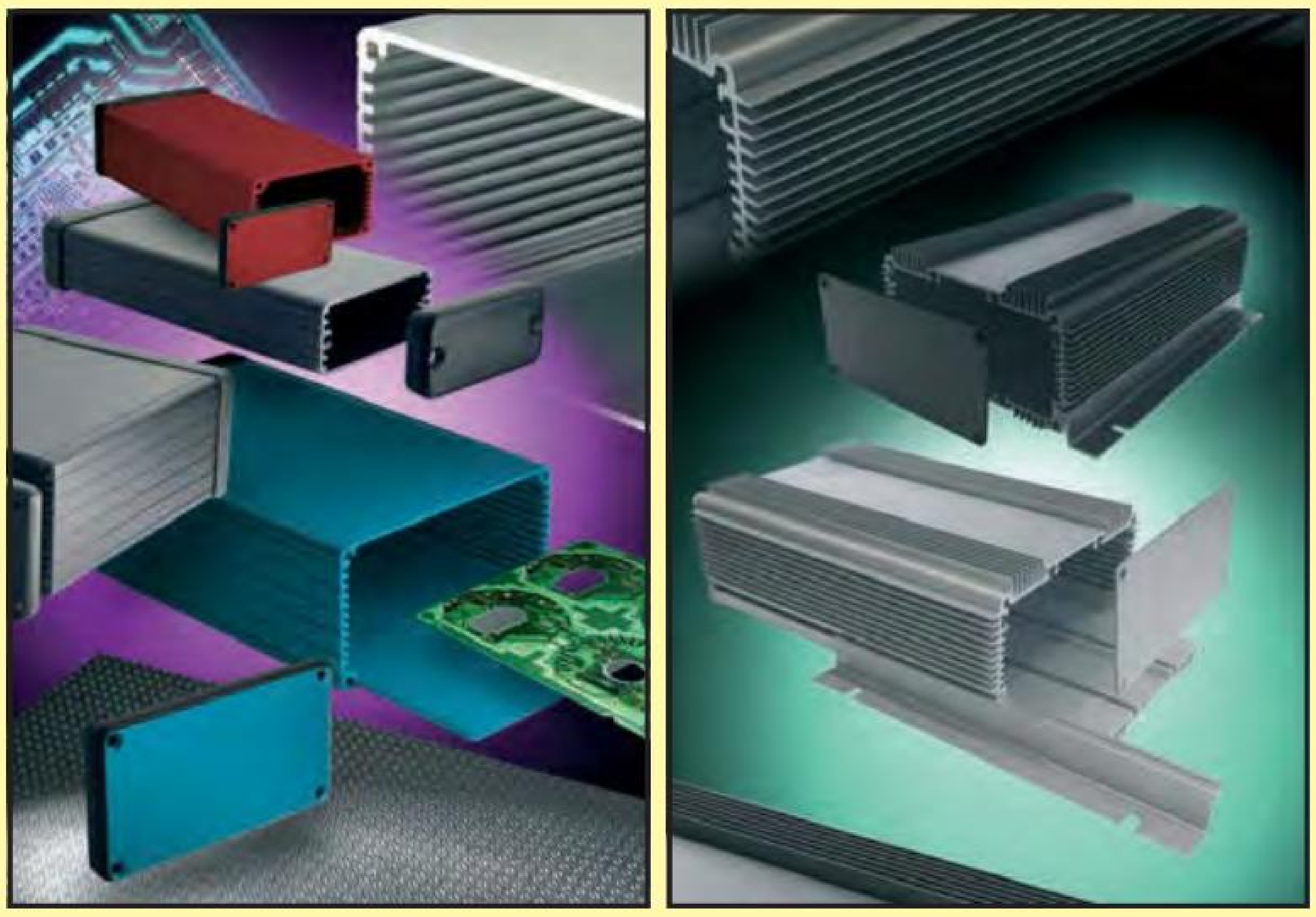
Predictably, government and industry have been slow to issue clear advice, so if you do nothing else today, warn a less savvy friend or family member. Here is a simple explanation of the basic scam which can be passed on and/or posted on chat room boards or in social media.

It's for you! ... no it isn't

Your home or mobile phone rings, and it is a recorded message warning of any one of many IT or banking problems (slow computer, insecure password, unpaid tax bill, hacked account, threat of arrest or prosecution, Internet access issue – the list is endless).

The recording ends with 'Press 1 to speak to someone'. If you Press 1, a human (usually with an accent, because many of the scam call centres are based abroad) comes on the line, which is poor quality because the call is being made at minimal cost over the Internet (VOIP). Your phone may well indicate that the call is coming from abroad, but even if it is a legitimate UK number don't assume that all is well. There are plenty of UK-based scammers and it's not difficult to fake the source of a call. Also, Internet chatrooms warn that pressing 1 to connect to a human can somehow route the incoming scam call to a high-cost premium line. I know of no way that pressing a single digit key can magically turn an incoming call into an outgoing call. But I am now asking Ofcom for a definitive comment and will report here.

The scammer then reads from a script with clever trick questions such as 'do you do home banking or online shopping or charity giving?' This reveals whether someone has banking details on their phone.



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If 'yes', the scammer tells the victim to go to the App Store or Play Store, search for a key phrase like 'Quick Support' and download and install an app such as Team Viewer. Once opened, the app generates a number which the scammer asks for. This gives the scammer remote access to whatever sensitive information is stored on the victim's device.

Apps like Team Viewer cannot be banned for these risks because they are legitimately used by genuine IT support staff to help people working at home.

Bottom line: if you are cold called by a computer-generated voice, hang up. If you have good reason not to hang up, and you talk to a human then:

- Do not follow any instructions to install anything
- Do not call any number offered for verification; it will very likely be answered by a scammer.
- Instead, do call the Help phone numbers printed on, for example, your credit card, phone bill or legitimate tax document.

US survey of telephone scammers

Just to give you a feel for the sheer scale of the telephone scam problem, a recent survey from the US states that, 'Scam calls are becoming the new normal with 75% of Americans targeted in 2020.'

'The survey of over 2,000 consumers and 300 business professionals showed that while voice calls were up almost 200% during the pandemic compared to 2019, the increase in calls is being exploited by scammers who are stealing money from unsuspecting victims and damaging trust in one of the most relied-upon communication channels.

'The survey shows that 75% of Americans were targeted by scammers in 2020, with millennials the most targeted demographic group (79%). Also, the data shows that during the same period, more than 50 billion spam calls were made to Americans in 2020 – 60% of which were fraudulent.

'Other info revealed shows that phone scams have real consequences, with more than 7% of people losing over $500 as a result of scam calls in 2020, with nearly 40% of all respondents reporting losing money to phone scams last year – with an average of $182 per person.'

On a lighter note

Finally, this month, I'd like to blow my own trumpet and introduce **www.tekkiepix.com**

This is a site I have just launched. It is a fun browse – as well as a research tool – for anyone curious about life Before Apple, Android, Google, Netflix, YouTube, Spotify et al. You will find pictures and stories about huge successes and spectacular failures. Marvel at the size, weight and cost of the first audio and video portables, and a multitude of other fascinating tales from the Fox vault.

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Marconi 2440	Counter 20GHz	£295
Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
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Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

HP/Agilent HP 34401A Digital Multimeter 6½ Digit £325 – £375

Marconi 2955B Radio Communications Test Set – £800

Whiskers are back and killing your electronics!

Techno Talk

Mark Nelson

No, this is not an April Fools' joke, and has nothing to do with hipster beards. A ticklish problem that plagued electronics in the past has made an unwelcome return. It's a 'disease' that is devious and creeps up undetected. Not every product is affected, and the remedy is not simple. The name of this pestilence is 'tin whiskers', and it's one of the causes of sudden death syndrome in PCBs using SMDs.

NASA summarises these whiskers very succinctly: 'First recognised as a problem during the 1940s by Bell Labs in the USA, tin whiskers are electrically conductive, crystalline structures of tin that can grow from surfaces where tin (especially electroplated tin) is used as a final finish. Tin whiskers have been observed to grow to lengths of several millimetres and in rare instances to lengths in excess of 10mm. Tin is only one of several metals known to be capable of growing whiskers.'

Destructive and unpredictable

The deadliness of this seemingly bizarre growth is considerable. When it occurs on the pins of semiconductor devices, it can short-circuit adjacent leads. Sometimes the short is only momentary (if the resulting current flow is strong enough to melt or 'fuse' the whisker), but if the short is maintained, it can result in total device failure. In application environments involving high levels of current and voltage, a highly destructive 'metal vapour arc' can occur. Here the solid metal whiskers are vapourised into a plasma of metal ions that are more conductive than the solid whiskers themselves.

The growth of these whiskers is also unpredictable, beginning after an incubation period that varies from seconds to years. However, recent research (published at **www.doEEEt.com**) sets out key characteristics of whisker growth:

- The filaments grow most often from tin-plated copper
- The most likely driving force for whisker formation is compressive stress in the tin layer. Stress on tin-finishes may also be induced mechanically, and consequently bending, scratches or nicks in the tin may favour tin whisker growth
- Whiskers grow spontaneously without any applied electric field or moisture
- Tin whiskers can grow either under ambient conditions, under reduced pressure or even in a vacuum
- The spontaneous growth of whiskers is an irreversible process.

What is not disputed is that whiskers have been proven to have caused the failure of satellites and heart pacemakers, and even caused the shutdown of nuclear power stations.

Public safety

The whisker problem was not a major issue until a decade or so ago, mainly because the 40% lead content of solder was effective at preventing whisker eruptions from the other 60% – tin. From around 2008, however, tin whiskers became reported as problematic again, triggered by the phasing out of lead in electronic component leads, with many parts using pure tin instead of lead-tin alloys. Lead is now banned by the Restriction of Hazardous Substances (RoHS) directive, and although RoHS originated in Europe, this directive now affects virtually every piece of electronics gear manufactured today or planned for the near future. Connectors, passive and active components, switches, and relays must now all be lead-free.

As semiconductor maker Maxim states, lead is recognised as a neurotoxin and is known to affect brain development, with children at greater risk than adults. The ban on lead in electronic products followed on from its removal from petrol, and paint, with the public no longer breathing in lead fumes and children no longer able to lick lead-based paint surfaces. This was a well-intentioned but ill-informed move. As Maxim points out, banning lead in electronics didn't make sense. the public do not ingest it and lead is not a contaminant of groundwater because it is not soluble in water, nor does it break down in the environment (it usually sticks to soil particles).

Blame the EU?

The leaded solder ban began in Europe, and according to Joe Smetana, now a principal engineer with Nokia in Finland but then a principal engineer and tin whisker expert with French telecoms equipment maker Alcatel-Lucent, 'The EU's decision was irresponsible and not based on sound science. We are solving a problem that isn't one and creating a bunch of new ones.'

It's hard to fault Smetana's logic, but despite this, EU officials retaliated that the regulations banning lead and other hazardous substances are needed to protect people and the environment regardless (huh?). In any case, the RoHS directive contains exemptions from the lead ban for companies in certain industries, such as aerospace, defence and, ironically, medical equipment.

Back with a vengeance

Moving rapidly forward to present times, the use of SMD integrated circuits with their little legs packed more closely together than a millipede's is near-universal. This means they are at high risk of tin whiskers growing directly on the leads themselves; alternatively, well-nigh invisible whiskers can become fractured and migrate elsewhere on the PCB, causing faults there.

So, what can practical electronicists like us do to avoid the tin whisker plague? For commercial products, with PCBs hidden out of sight and populated with densely packed SMDs, the answer is not a lot. But if you build your own projects that employ 'electronic millipedes', the remedy is to protect the components immediately after soldering to mitigate the subsequent growth of whiskers. One remedy mentioned in an online forum suggests that a good scrub with a nail brush might do the trick, followed by a 'conformal' coat of epoxy or polyurethane varnish. 'Might' is the operative word, because Trizo Ltd warns that tin whiskers have managed to penetrate polymer coatings, causing an even greater risk of critical electronic system failures.

Alternatively, simply don't use lead-free solder on your projects! Stick to the good old 60/40 tin-lead formula; it's far less prone to tin whiskers, perfectly legal for home construction and melts at a lower temperature, meaning your soldering iron's tip will last longer. Result! (Do remember to wash your hands *properly*!)

Win a Microchip Curiosity HPC Development Board

Practical Electronics is offering its readers the chance to win a Microchip Curiosity HPC Development Board (DM164136) – and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these products.

Microchip's Curiosity HPC is the perfect platform to harness the power of modern 8-bit PIC microcontrollers. Its layout and external connections offer unparalleled access to the Core Independent Peripherals (CIPs) available on many newer 8-bit PIC MCUs. These CIPs enable the user to integrate various system functions onto a single MCU, simplifying the design and keeping system power consumption and BOM cost low.

This board provides flexibility for experimentation through an application header with ground (GND) and supply voltage (VDD) connections. It also includes a set of indication LEDs, push-button switches, and a variable potentiometer. Additionally, it features two mikroBUS headers to accommodate a variety of plug-in Click Boards that can be used in application development. All connections to the mikroBUS headers, LEDs, switches and potentiometer are labelled with the microcontroller port name for ease of programming. The full pin breakout of the microcontroller is provided to expand the flexibility of the Curiosity HPC Development Board.

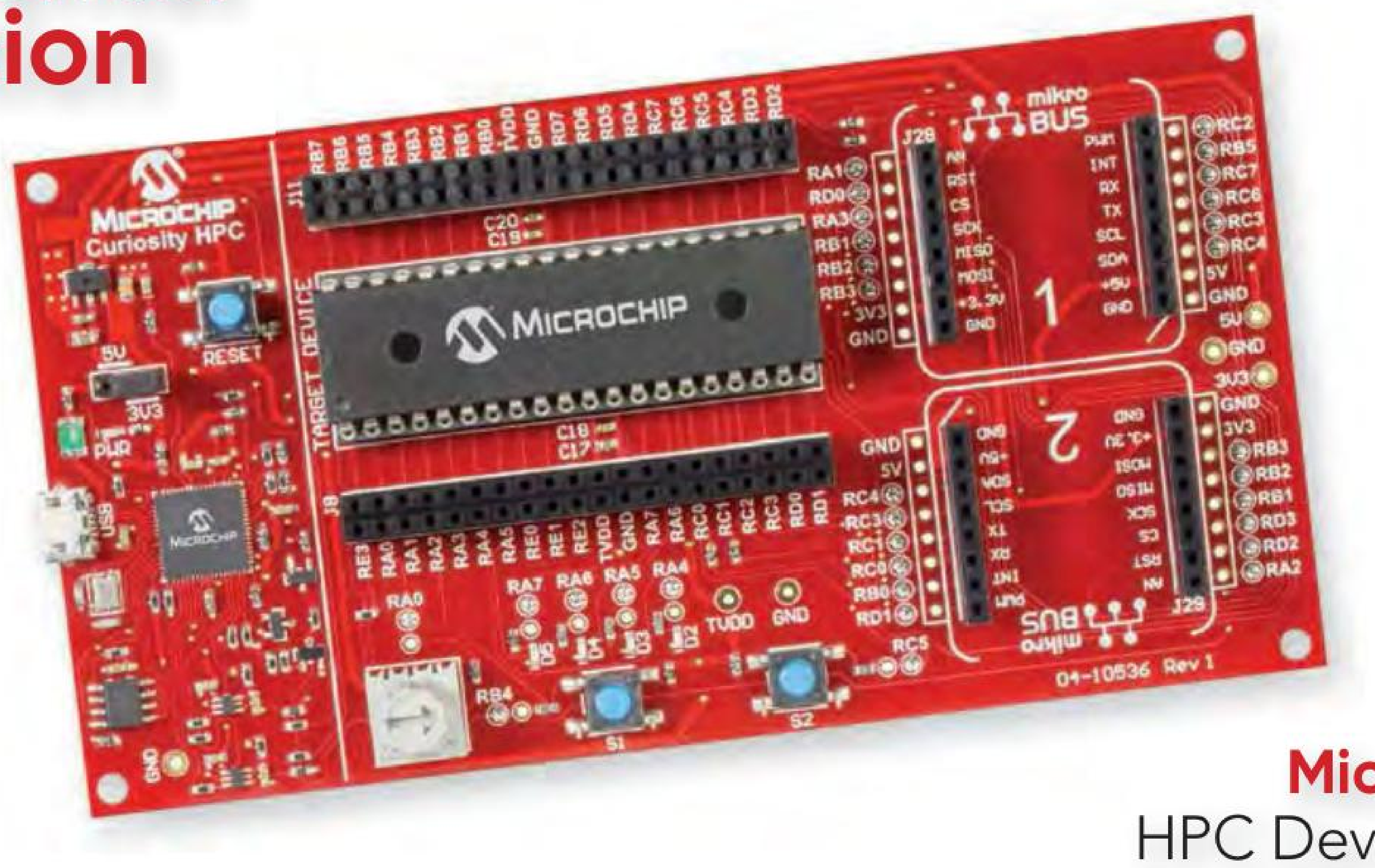
The Curiosity HPC Development Board can also evaluate and support the new Microchip PIC18 Q84 Family, the first PIC18 microcontroller family that can be used to transmit and receive data through a CAN FD bus. Accompanied by an extensive array of CIPs that handle a variety of tasks without requiring CPU intervention, Microchip's PIC18 Q84 family cuts both time and cost when connecting systems to a CAN FD network.

It also includes the following features:

- Accommodates 40- and 28-pin 8-bit microcontrollers
- Fully compatible with the MPLAB Code Configurator and MPLAB X v3.05 or later.

Worth $40.00 (approx £29.00) each

Free-to-enter competition



Microchip Curiosity HPC Development Board

How to enter

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Closing date

The closing date for this offer is 31 March 2021.

December 2020 winner

Adam Hill-Merrick

He won a Microchip MPLAB Starter Kit for Serial Memory Products

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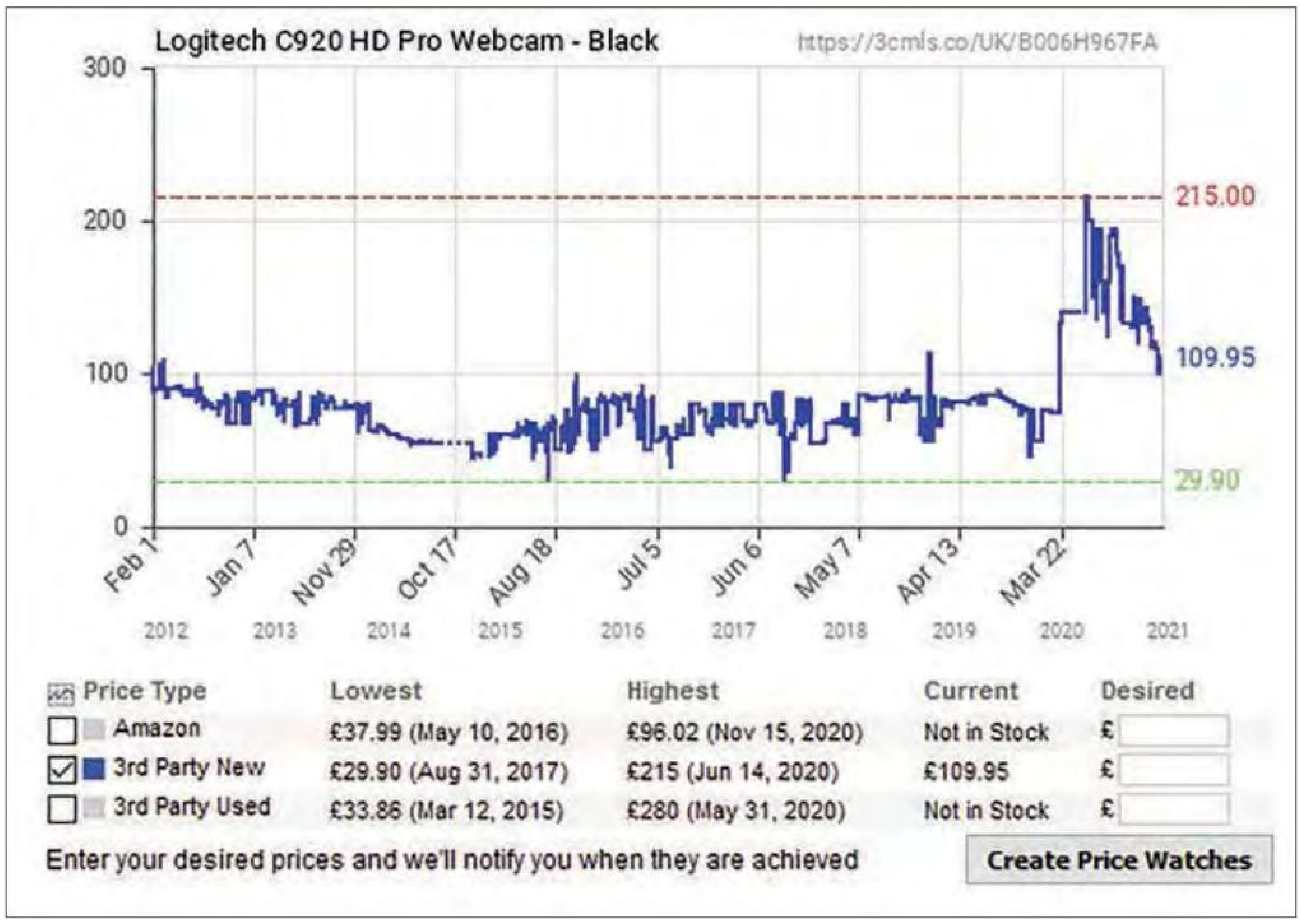
Net Work

Alan Winstanley

This month, *Net Work* asks if hydrogen is a viable alternative to fossil fuels and batteries for cars; revisits old *PE* fora and offers a route to avoid 'Zoom shame' if your bookshelves are letting you down!



Price Type	Lowest	Highest	Current	Desired
☐ Amazon	£37.99 (May 10, 2016)	£96.02 (Nov 15, 2020)	Not in Stock	£
☑ 🟦 3rd Party New	£29.90 (Aug 31, 2017)	£215 (Jun 14, 2020)	£109.95	£
☐ 3rd Party Used	£33.86 (Mar 12, 2015)	£280 (May 31, 2020)	Not in Stock	£

Enter your desired prices and we'll notify you when they are achieved

The Cameliser browser plugin tracks Amazon prices. It shows how prices for this ten-year-old Logitech webcam leapt in lockdown last year.

Thanks to Internet access, life for many users during lockdown has somehow stumbled along, and we have been forced to accept the need for video calls, webcasts, online tutoring and multi-user video conferencing. Whether it's a local meeting such as the chaotic one infamously held by Handforth Parish Council (see: **https://youtu.be/BujIT9NSDoM** – Channel 5 TV news), or simply checking in with other office colleagues, working from home (WFH) is here to stay in one form or another. This new way of doing things has paid dividends for the online bookseller and book recycler Bookbarn International (www.bookbarninternational.com) who sell used books for TV and film sets as well as for individual users. They report an uptick in sales because prominent people want to look more 'learned' and 'well read' when appearing on webcam. No stock images of *faux* library shelving for them, when a more authentic way is to line their bookshelves with some weighty and well-thumbed titles – the book firm supplies anything from an entire shelf to a whole bookcase of them, they say. You can even rent them by the yard, with a wide choice of spine-based themes (Penguin/leather/textbook)!

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In recent *Net Work* columns, I highlighted the problems of sourcing a PC webcam, because stocks of them have dried up thanks to WFH. Due to the uptake of mobile devices with built-in cameras, there's no incentive for manufacturers to update webcams, and although the author's desired Logitech C920s ('s' for privacy shutter – see later) is nearly a ten-year-old design, it still lingers on sale. Branded webcams have sold out almost everywhere thanks to WFH, and *Net Work* readers might remember how one, sourced by the writer via Amazon Spain last November, 'mysteriously' disappeared without trace from their local UK depot just before Christmas.

Eventually though, my four-month quest for a Logitech webcam has finally borne fruit after striking lucky with the slightly faster Logitech C922. This near identical 1080p USB camera is optimised for gamers and streamers, offering 60 frames per second at 720 px. It's a good autofocus webcam for Windows 10 or Mac, and also bundles a very small tripod but, disappointingly, one or two legacy features such as the clever 'follow my face' function are not included in Logitech's 'Capture' software. Nor could I make it work with Windows Hello (in Windows 10, simply hit the Windows key and type 'Hello' to access Face sign-in). This may be a firmware issue.

A streaming setup

This camera goes further than an ordinary Plug and Play webcam does though, as the package offers chromakey processing, titling and a few effects, along with 3-month XSplit Premium licence for broadcasting, creating YouTube videos or streaming. A PC webcam like this therefore offers a good introduction to creating

It's great – if you can get one. Logitech's C920s is a Full HD 1080p USB webcam with stereo microphones and (at top) a privacy shutter.

your own videos, and more details of XSplit's popular broadcast software is available at: **www.xsplit.com**

Consider too the pricier Logitech Streamcam, while business users will want to look at the more expensive and secure Logitech Brio.

Many such products are listed on Amazon, but their pricing practices can trip the unwary: the indispensable Cameliser Amazon price tracker (**www.camelcamelcamel.com**) alerts buyers about price drops and, sure enough, the webcam in question suddenly fell to £72 for a few hours before rising to £140 again, and then it sold out before returning on sale at £95. It is definitely worth taking your time and tracking prices closely before committing to more expensive purchases where possible.

Finally, the privacy shutter, if that's an important issue for users. The largely unavailable C920s webcam bundles a flip-down shutter, but the same-sized C920 and C922 do not. The simple answer was to buy a compatible one for £4 on eBay which simply clips onto the camera body. It works perfectly, but of course it doesn't silence the microphone!

A Brexit bottleneck

When shopping online in this post-Brexit era, one major issue to bear in mind is that Anglo-European trade now has geographical borders to contend with. Amazon quoted an all-inclusive price (£89) for the above webcam, which in the event was airfreighted from Italy and delivery maybe took a day or two longer due to customs clearance. In this case there were no extra costs, VAT or import duty to pay. However, international trade is being forced to adapt to pre-single market conditions, which involves goods clearing customs and paying any applicable import duty. British buyers can import goods up to £135 in value free of duty (except for excise goods like tobacco and alcohol), and VAT should already have been included in the purchase price. Exceeding that £135 threshold by one penny opens a can of worms for buyers: in many cases the courier or freight forwarder may pay import duty on your behalf to speed up delivery, but you will then have to stump up duty, VAT and agent's 'brokerage' fees plus VAT before they deliver the goods. Sometimes these added costs outweigh the import duty itself.

With containerloads of goods currently stacked up in British and European ports awaiting customs clearance, and vessels moored offshore because the docks are running out of space, it was inevitable that international trade would buckle under pressure after Brexit. There will undoubtedly be plenty of wrinkles to smooth out when importing or exporting goods in this new era, and it's yet to be seen how well, for example, Amazon or eBay's Global Shipping Program will cope with the added need for customs clearance. Once the dust settles and more experience is gained, though, the process should hopefully become much smoother. For now, the risk of incurring hidden extra costs must be borne in mind by consumers buying from the EU. The excellent UK Government website is commendably clear and explains import taxes (**www.gov.uk/goods-sent-from-abroad/tax-and-duty**). Importers and exporters may also want to see: **www.gov.uk/trade-tariff**

Our legacy projects live on

Our postbag proves that many old magazine projects published decades ago still capture the interest of electronics constructors around the world. Recently, someone enquired about the *PIC Virus Zapper* from the March 2002 issue! Readers love to describe how they recently restored and updated an old project ready to face the 21st Century. We enjoy hearing your stories and recollections, so do keep them coming.

Quite a few constructional projects have a special place in our readers' electronics heritage, especially our library of PIC-based microcontroller projects dating back to the early 2000s or before. Many regular enthusiasts will recall the pioneering PIC microcontroller projects created by our late Technical Editor, John Becker. John was self-taught from scratch and singlehandedly carved out the hobby market for DIY PIC projects when '*EPE*' (as we were called then) decided to major on Microchip's brand of PIC microcontrollers. We were also the first hobby electronics magazine to give away PIC project source codes for free, which at last empowered readers to program their own microcontrollers and study or modify the source code for themselves. Very many readers remain grateful for John's tireless work in designing ingenious circuitry along with the source code and DOS or Windows-based software that accompanied some of his major projects and series.

We still receive requests for old PIC project source codes from time to time, and even though the new *PE* website does not carry legacy material earlier than 2010 (**www.electronpublishing.com/library/**), the writer does maintain a legacy website (**www.epemag.net**)

Practical El
FREE

John Becker (right), late editor of *Practical Electronics*, paved the way for our PIC projects. Seen here with Sir Clive Sinclair (left) at *PE's* 25th birthday in 1992.

where our oldest files dating back to 2000 (and earlier) are still available.

Starting in 1996, in the very early days of the web, our file area was hosted on a now-closed FTP server in Southampton, UK, but eventually the downloadable files were given a popular web-based 'tree' front end to make access easier. This was migrated to **www.epemag.net** where it is visible from the left-hand menu 'Legacy PIC Source Code'. Since FTP file transfer is no longer supported by mainstream browsers anyway, this web-based alternative offers a simple way of downloading old source code files for legacy projects. Each project included a **readme.txt** file which has proved handy 20 years later on. Note that the website itself is on 'R&R' and is only updated periodically.

Currently, our legacy website at **www.epemag.com** is still running and hosts older material and legacy project details for the time being. It is no longer maintained. Also, don't forget you can buy entire back issues of *EPE*/*PE* for immediate download or on CD, see our online store for details: **www.electronpublishing.com/product-category/pe-back-issues/**

Is the future H-powered?

I'm grateful to regular *Net Work* reader Ken Wood who writes: 'Apropos your column in the Feb 2021 issue on electric vehicles, it seems we hear very little about hydrogen as a source of energy for road vehicles, and yet (on the face of it) hydrogen would solve many of the issues which plague EVs.' Ken is right to highlight the hydrogen fuel alternative and he suggested some possible options and benefits of hydrogen-fuelled (or dual-fuelled) cars and trucks, and a lot of interesting correspondence followed!

A highly respected British motoring journalist claimed many years ago that the future lay in hydrogen fuel-cell powered vehicles rather than in rechargeable battery-power. Hydrogen-powered vehicles have zero emissions and hydrogen is itself the cleanest of fuels. The British government has its own Office for Zero Emission Vehicles (OZEV) which is funding projects such as hydrogen-fuelled London Ambulances, but hydrogen-fuelled transport has yet to gain a toehold. The public is getting used to the idea of hybrids, there are next to no hydrogen stations yet and the cost of producing and distributing the gas is currently high. There is also a dearth of viable fuel-cell electric vehicles (FCEVs) themselves. Honda UK was exploring hydrogen production and has floated a hydrogen-powered car (the Clarity) but is now closing its UK site altogether; FCEVs potentially offer major advantages over EVs, but the infrastructure to fuel them simply isn't built yet.

China's latest electric microcar from Wuling is outselling Teslas.

That is not to say that FCEVs are dead in the water. In Spain, there are plans to build up to 120 hydrogen stations by 2025, while in Britain there are proposals to produce 'green' hydrogen offshore, using wind turbines, in a world-first project called 'Dolphyn', an acronym for Deepwater Offshore Local Production of HYdrogeN. The ERM Group behind it has been awarded £3m of government funding to develop Dolphyn at Aberdeen, Scotland. In South Korea, by comparison, industrial gas manufacturer Linde has partnered with Hyosung to build an entire hydrogen infrastructure network costing £200m.

In January, the consultancy firm MJB&A, a member of the same ERM group, published a report on how it sees the EV market over the next 5-10 years: it states that, 'globally, auto makers have committed to spend $257bn (up from $185bn in the last report) on vehicle electrification over the next 10 years, including at least $2211bn on domestic US manufacturing, supporting the view that the auto industry has embraced the vision of electrified mobility and the EV market is on the cusp of a period of significant growth.'

Early adopters of EVs aren't always having a good time of things, though. A recent blog on *Automotive News Europe* describes some rotten experiences of trying to run a new VW ID3 (see *Net Work*, January 2021) using a nascent EV charging network around London, with myriad problems with payments, mobile apps and broken charging points. (Incidentally, you can peek inside a Volkswagen electric car battery recycling plant at: **https://youtu.be/Qi8Y2lF7Luw**).

All of this is enough to put many motorists off the idea of buying an electric vehicle altogether. Hydrogen fuel remains very much a possibility in the future, but clearly not just yet. I see it perhaps as the ultimate fuel solution waiting in the wings: if it was the light bulb market, perhaps battery-powered EVs can be likened to CFL bulbs, a stopgap measure needed until decent LED bulbs arrive. Ken has created a Facebook group called 'Hydrogen power for vehicles' to publicise and promote the idea of FCEVs.

Meantime, the EV market in China grows unabated and another brand, Wuling, is powering ahead with the production of extremely low-cost ($4,000) electric microcars designed for the younger driver commuting around town. For size, think of a Daimler 'Smart' car. The Wuling Hong Guang Mini EV, to give it its full name, is a joint venture with General Motors and China's SAIC (also the name behind MG Cars) and has overtaken Tesla as the top selling EV car in China, manufacturing about 30,000 a month. It's aimed at the Chinese home market – for now. It doesn't stop there: take a look at Chinese car maker Nio (in Mandarin it's *Weilai*, or 'Blue Sky Coming') which produces a range of very smart-looking EVs, and is working on Formula E racing and autonomous cars too. You can see more at: **www.nio.com**

Nio is presently aimed at the Chinese market, but they and other brands like

Renault plans to relaunch the much-loved Renault 5 as an electric vehicle.

MG and Xpeng (see last month) are part of the huge groundswell in Chinese EV development and manufacturing. They may face tough competition from European makers though: presently no *Net Work* column is complete without a photo of an EV and France's Renault has slated the relaunch of the much-loved Renault 4 and 5 as electric cars.

A Chat Zone chestnut

My thanks go to regular reader Edward Chase who wrote: 'Sadly EEWeb [an online electronics forum] is proving to be a very poor substitute for the excellent old *EPE* Chat Zone. When I post things there, I get almost no responses and the volume of posts that interest me is generally low. Is it time to have a rethink? Perhaps have a blitz to encourage *PE* readers to post more to make it work or set up a new forum that maybe is moderated by some long-term *PE* readers rather than you to save you the considerable effort. There are several commercial forum hosting services that work well, and some will be free to use. I have no one who I can talk to face to face, even in non-Covid times, about detailed electronic matters, so forums provide an essential service for me.'

Thank you for writing, Edward. We certainly know that the old *EPE* Chat Zone forum was the favourite go-to place for many readers to share their views, get help with projects or generally share some banter. It was not pre-moderated by me but was closely monitored to keep it a friendly, pleasant and helpful forum where *EPE* readers could swap notes and help each other out. Hopefully, I got the balance right – most of the time anyway!

Its Discusware Perl-based server software was extremely robust, but it was very clunky and lacked features that some readers wanted to see (though others didn't mind). After a great run starting from 2005, several factors contributed to the ultimate closure of this forum. A key one was the competition for traffic, as users found many other places to go when the web exploded, including other forums or Facebook. There is only so much jam to go around, and the number of posts dwindled very dramatically as users moved on, or their interests changed; it was barely a handful of posts a week in the end. To make things worse, Discusware suddenly shut up shop and vanished overnight.

This left us with a legacy, unsupported forum and the introduction of GDPR data protection rules made the maintenance of users' privacy and security a worry. It eventually went into read-only mode, and the level of interest remained extremely low. Finally, a web server upgrade knocked out the Chat Zone forum software for good, something we had always pre-warned could happen at any time without notice.

I managed to grab a portion of the old Chat Zone messages and rebuild them on my own web server. To give you a taste of olden times, there is more at: **www.epemag.net/chatzone.html** but some broken links or other oddities are evident here and there. I hope it brings back some memories.

EEWeb is a decent quality electronics engineering forum (see: **www.eeweb.com/forums/**) and we were given a small corner or 'category' to operate our own area, but it was a poor fit and it never really took off. The interest again reflected the minimal traffic levels as seen in the old Chat Zone. Then a change of staff at EEWeb more or less severed our connection with them, which is why the forum has largely been de-emphasised. When there's very little traffic to begin with, it's hard for us to justify building a new one in the hope of building some sustainable traffic, especially when there is far more competition today for people's time from the web, streaming video and social media. You are right to say that running a forum is very time-consuming; it's also extremely onerous due to the pressure from data protection law and the GDPR. Any data breach, even though not our fault, causing a loss of personal data risks substantial and possibly ruinous fines from a largely unsympathetic Information Commissioner. One small UK agency was fined £66,000 for a fairly minor technical breach. This matter is under review, though and we welcome more feedback and ideas from readers.

See you next month for more *Net Work!*

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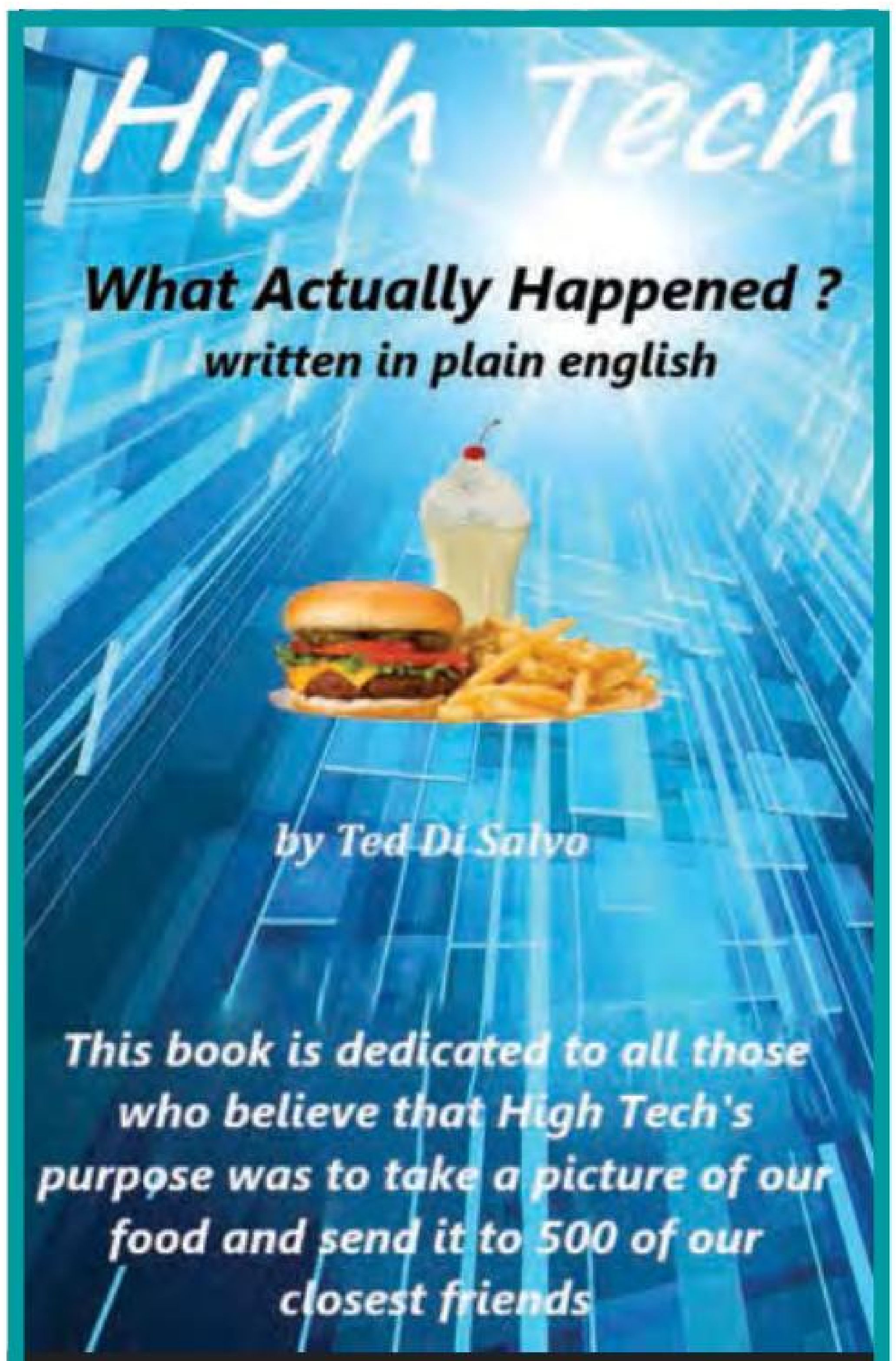

High Tech
What Actually Happened ?
written in plain english
by Ted Di Salvo
This book is dedicated to all those who believe that High Tech's purpose was to take a picture of our food and send it to 500 of our closest friends

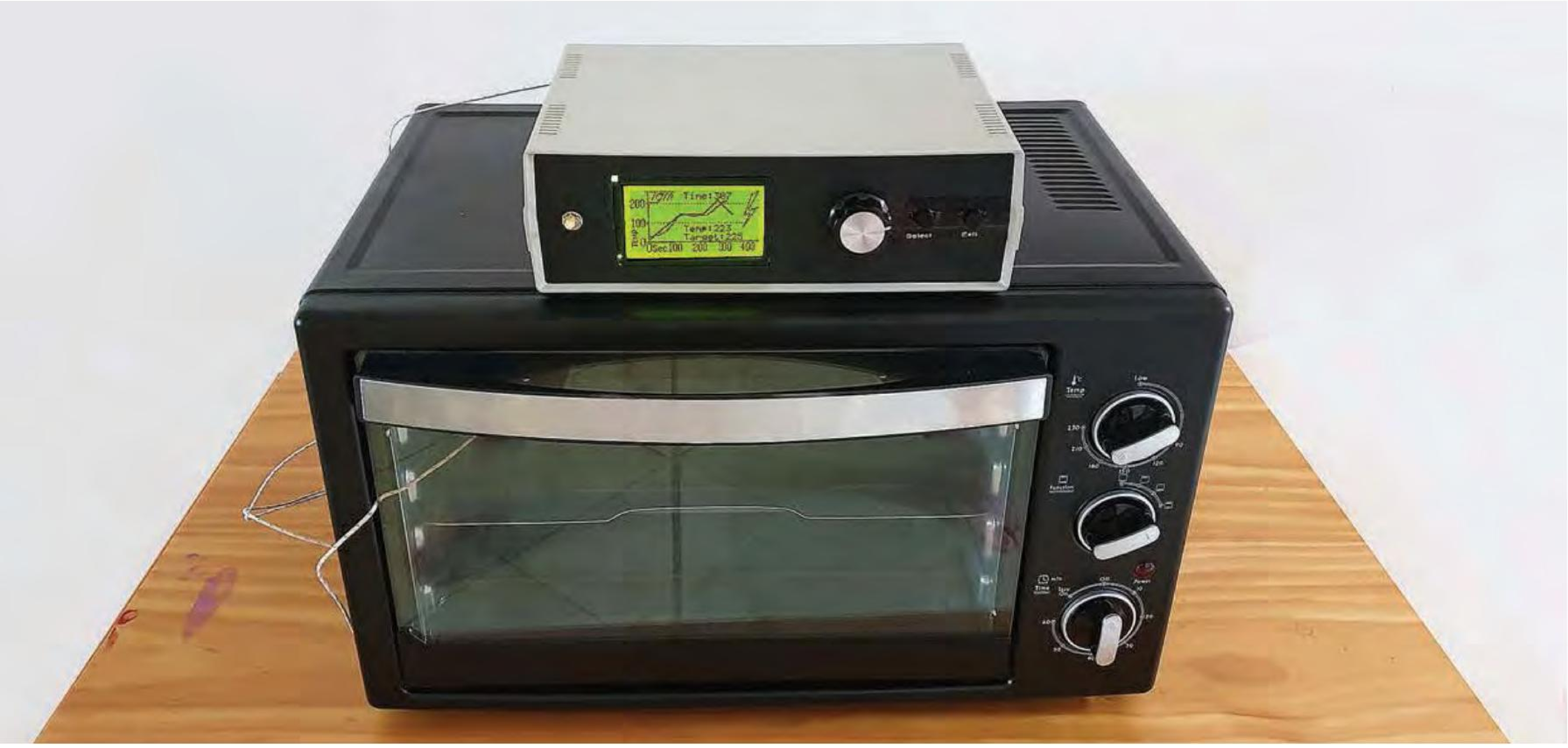
70 years of technological developments have brought us to today. Some of these advances were monumental and game changing in their own right. Some significant spin offs have revolutionised many unrelated areas. The author has had a front-row seat through most of this revolution and puts it in perspective in plain English.

Available on Kindle or in paperback at Amazon

DIY SOLDER REFLOW OVEN WITH PID CONTROL

Part 1

by
Phil Prosser



Make short work of soldering boards full of surface-mount components with this low-cost and easy-to-build DIY solder reflow oven. It's quite cheap to build but it runs your PCB(s) through a temperature profile much like a professional reflow setup costing thousands! It can also be used to 'bake' components, cure glue or paint, or any other task where you need to hold something at a stable, elevated temperature for some time.

There are several reasons that SMD components are becoming so common, to the point that it's becoming very difficult to avoid them.

It is due to the need to make products ever smaller, and the lower cost of mass manufacturing these parts and the boards that use them. As a result of these and other factors, most manufacturers do not release new components in anything but surface-mount packages.

If you have young eyes, a microscope or good magnifying glass and some patience, this is not such a problem. So while we are conscious that surface-mount devices (SMDs) present a challenge to some, we use them where we need to. However, some of the smaller packages present a real challenge, especially those with thermal pads in the middle of the device, and leadless packages to name a (very annoying) few! These cannot be soldered with a regular iron.

If you see yourself building projects with SMD parts and especially the pesky ones that do not lend themselves to hand SMD soldering techniques, then this project is for you.

Alternatively, if you are looking for a simple way to control the temperature of an electrically heated oven, this is also a very handy device for that job.

Working with SMDs

We have, at times, used a hot-air blower on a device, to heat it and the board until a thermal pad under an IC reflows.

This generally works, but it's a bit of a hit-and-miss method, requires quite a bit of skill, and can regrettably lead to the demise of expensive chips!

Not only that, but a hot-air blower invariably tries to blow the SMDs out of position!

In commercial manufacture, these devices are generally 'reflow soldered' in one form of oven or another.

This project presents a more controlled alternative to our brute force methods. It follows in the footsteps of others who have repurposed a toaster oven as an SMD reflow oven (do see Mike Hibbett's *Beta Layout's Re-flow Oven Kit and Controller* review in our April 2014 issue).

What is reflow soldering?

Reflow soldering is a process where solder paste is applied to the pads on a PCB, the SMD components are loaded onto this paste, and the entire PCB goes into a reflow oven.

This subjects the board to a temperature profile that heat soaks the components, then briefly bumps the temperature up to melt and 'reflow' the solder paste.

The entire process in a commercial environment is automated, with robots loading the components and the reflow oven having sophisticated thermal control and the ability to ramp the temperature up and down from the reflow point very quickly.

While that's nice, you don't need all that complicated a rig to get a good result. This project repurposes a regular toaster oven to allow you to reflow one or several boards.

We are using tin/lead solder, and recommend that you use this too, due to its lower temperature requirements. It may be possible to use such a rig with lead-free solder, but we haven't tried it.

This allows you to solder pretty well any SMD to a PCB, and to handle those pesky devices with heat spreaders and LCC packages. It works just as well for your usual resistors, capacitors and semiconductors. And the great thing is that you can solder many components at once; a whole board (or even a few) is possible, depending on the design.

We should point out here that some board designs may not be suitable for reflow soldering.

It's generally best to have a consistent amount of copper across the PCB to use this technique. A board with a large ground plane on one side and sparse tracks on the other will not heat evenly, and so you could end up with unmelted solder paste at one end, or in the worst case, a burnt PCB at the other!

Having said that, a great many SMD-populated boards can be soldered in a reflow oven. So it's a very useful tool.

The simple method

With a stopwatch, a K-type thermocouple and some practise, it is possible to work out an 'on/off' timing sheet that you can use to reflow SMDs manually. But this is a bit hit and miss, and if you have a moment of inattention, things can come unstuck.

This project takes the guesswork out of using an oven for reflow, and the controlling computer should not have any moments of inattention!

Features

- *Self-contained controller converts a toaster oven into a reflow oven*
- *Temperature profile follows standard reflow soldering profiles closely*
- *Closed-loop PID (proportional-integral-differential) temperature control using a thermocouple and solid-state relay*
- *Can hold oven temperature at any point in the range of 20-230°C (eg, for 'baking' components or curing paint/glue)*

What is 'PID' control?

There are many ways to control a temperature. The simplest is to switch the heater on if the target is below the setpoint, otherwise, switch it off. This is sometimes called 'bang-bang' control; it is either flat out or off.

This works, but is subject to errors and lots of overshoot, as it does not consider how far the sensed temperature is from the setpoint, nor how fast the temperature is approaching the setpoint.

A proportional/integral/differential (PID) controller addresses these shortcomings. It has parameters for:

- Proportional control, ie, linearly related to the difference between the two temperatures.
- Differential control, ie, how fast the temperature is changing; this affects how hard we drive the temperature. This uses the rate-of-change of temperature to minimise overshoot.
- Integral control, ie, looking at how much the sensed temperature missed the target. We integrate the error in temperature and feed this into the algorithm to 'trim' the error out long-term.

This seems complex, but don't worry. The supplied software handles all the details, and comes with a good initial set of parameters which give you a decent starting point.

The main reason we're using PID control is to minimise temperature overshoot. The toaster oven has a lot of thermal mass, as does the heating system, so it is slow to respond.

Once the element has been on for a while, after you switch it off, the temperature keeps rising for quite some time. This makes a 'bang-bang' controller very prone to overshoot. The differential term in the PID controller helps us tame this.

Despite this, it's likely that your oven will still experience some overshoot. This can happen for several reasons; it may be that the PID parameters used are not ideal, but the fact is that the parameters can really only be tuned properly for a single temperature.

Given that it's crucial to avoid overshoot at higher temperatures, you're more likely to experience it at lower temperature set points.

The controller's user interface lets you adjust the PID variables to tune the controller for various ovens. Inside our controller software, we have put modifications into the PID controller settings that reduce the drive and increase the damping for temperatures below 100°C, in an attempt to mitigate the aforementioned low-temperature overshoot problem.

We also disable PID control for the last 'reflow sprint', to get this over with as quickly as possible.

The result is that the errors are relatively small; certainly, a lot less than a 'bang bang' controller would produce.

This project uses hardware which was previously used in the *DSP Crossover* (Jan-Mar 2020). However, the firmware loaded into the PIC32 microcontroller is, naturally, quite different.

The code is available for download from the April 2021 page of the PE website; the PCBs are available from the Practical Electronics online shop.

Most of the other components should be easily obtainable from your favourite parts supplier, although there are a few specialised components whose sources are shown in the parts list.

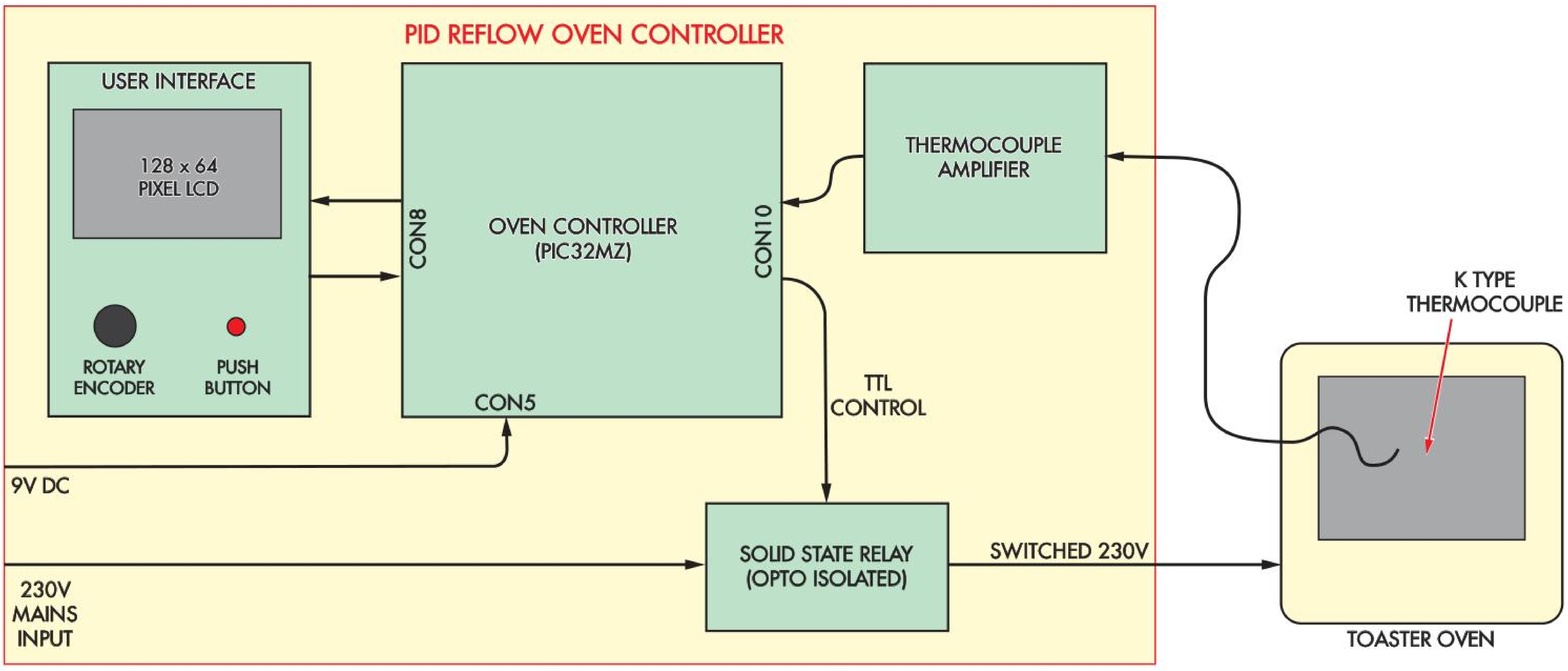


Fig.1: a block diagram showing the basic operation of the DIY reflow oven. The oven temperature is sensed by a thermocouple placed within, and this is fed back to the PIC-based controller board via a thermocouple amplifier. It then controls the temperature by switching the oven element on or off via a mains-rated solid-state relay (SSR).

What is it?

I have designed a proportional-integral-differential (PID) controller which oversees the oven heating, with user-defined heat soak and reflow temperatures. I have determined the PID coefficients that work for my test oven, but they are 'tunable' for your oven (you may find that my values work fine). The basic configuration of the device is shown in the block diagram, Fig.1.

The control block at left is built using a PIC32MZ-based microcontroller board that we have used in two projects already (more on that later). It senses the oven temperature using a K-type thermocouple and a prebuilt thermocouple amplifier module. A solid-state mains relay controls the oven heating elements, and it's rounded off by an LCD so you can see what's going on, and a basic power supply.

In the development process, I pulled a couple of ovens apart intending to integrate the controller into the oven itself. This is definitely possible, and experienced constructors may take this approach.

But for this project, we have chosen to present a standalone controller for a few reasons.

First, once you are inside the oven, you are presented with a lot of exposed live parts, and every oven will be different, so it's difficult for us to describe how to do this safely.

Secondly, there is generally no insulation between the oven wall and the equipment space behind the controls. Typical PVC wiring is rated to 70°C.

While some types of wire can operate at higher temperatures, they still cannot withstand the temperatures at which the oven operates.

So you would have to choose carefully where to mount the controller, and insulate it thoroughly against heat.

Note that oven manufacturers use fibreglass-insulated wiring and crimp/weld connections exclusively. This is a good choice for an oven but not conducive to DIY modification. So we decided to leave the oven completely unmodified.

One of the nice features of this controller, besides the ability to follow a reflow-soldering profile, is the ability to accurately bring the oven up to a set temperature and hold it there. Now that I have this feature, I often use it for curing paints and glues at 60°C.

If you recall your chemistry lessons, for every 10°C (or 10K) increase in temperature, chemical reactions typically double in speed. I'm impatient, so using the oven to fast-cure paints and glues is hard to resist!

Note that many SMDs also require you to bake them at a particular temperature for a particular time before soldering if their packages have been open for more than a few hours/days/weeks. This is usually printed on the packaging. This oven is ideal for doing that too.

Limitations

There are one or two limitations that we have accepted in this project:

- The choice of oven limits the temperature ramp rate. We chose a 1500W oven, and it works well. We recommend that you use an oven with a similar power rating.
- Convection ovens are a touch more expensive. We tried both and found convection ovens to be a better choice, but not by enough to recommend that you spend the extra cash. One limitation of a convection oven is that, unless you modify the oven, when we switch the element off, the convection fan also switches off.
- We have not built a 'door opener'. At the end of the reflow cycle, professional ovens cool the board reasonably quickly. In this project, you need to open the door of the oven a crack yourself. This results in a cool-down that is remarkably close to the recommended temperature profile.

One advantage that we did note when using convection ovens (which are basically toaster ovens with fans) is that they have reduced overshoot at low temperature settings. That is not a big deal for SMT reflow but makes a surprising difference if you're running the oven at lower temperatures, like 60°C, for drying paint or curing glue.

However, to get this benefit, you need to modify the oven so that it has a separate mains supply for the fan, to allow it to run all the time and not just when the heating element is on.

Because of the safety implications of doing that, we suggest that only experienced constructors with plenty of mains wiring experience take on this job.

The overshoot on a non-convection oven going from 20°C to 60°C is about 10°C, while for a convection oven with the fan wired to run constantly, it is closer to 3°C. Setting the PID parameters to avoid this with a non-convection oven would result in super-slow heating times.

Safety

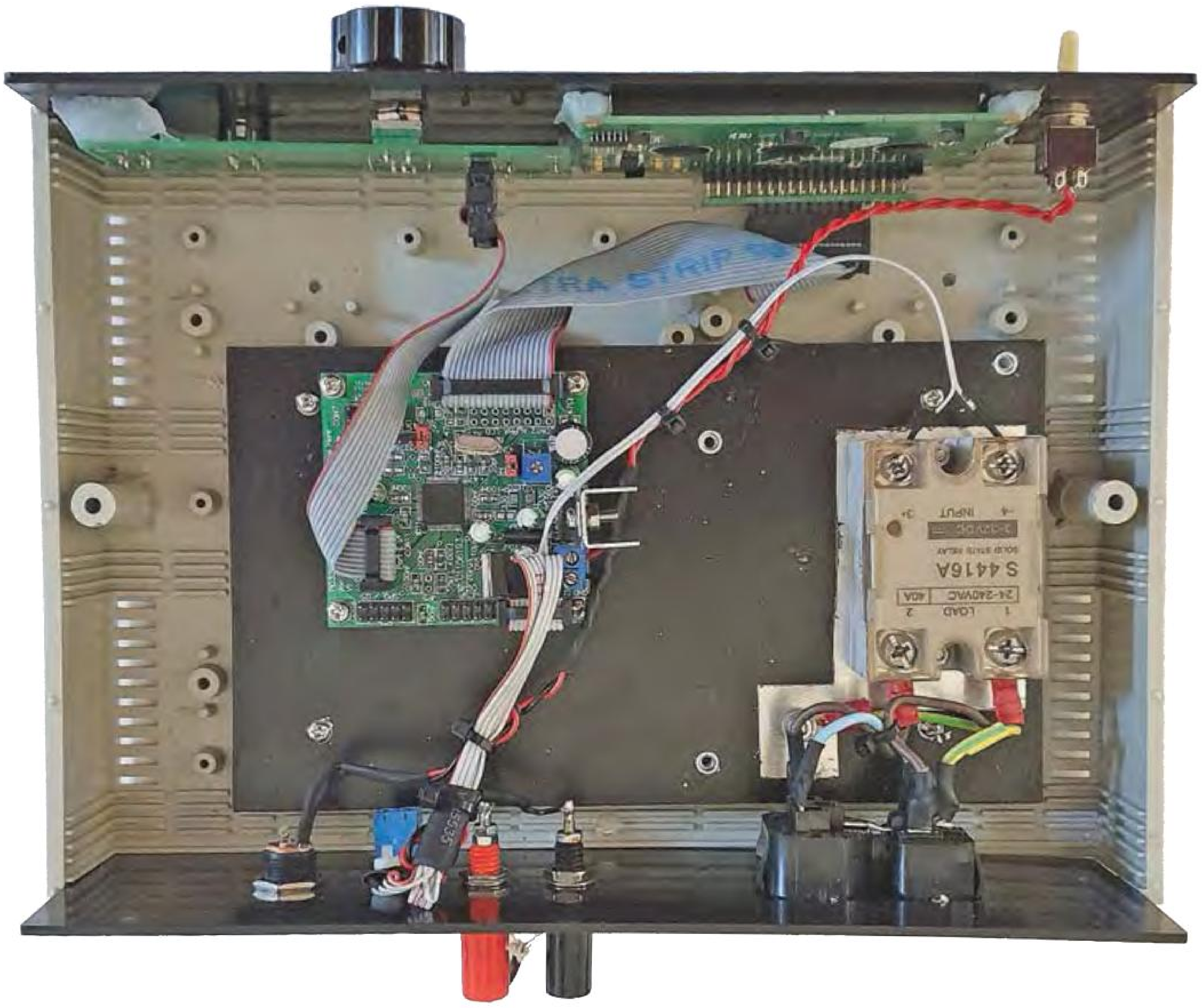
This project has been developed to minimise the amount of mains wiring that you need to do. The only mains wiring we need to do is to connect the solid-state relay in the controller to a dual IEC mains socket.

All other parts of this project operate from a 9V plugpack, so most of the assembly work is easy and safe.

Choosing an oven

We bought the toaster oven shown here from a general household retailer. You need an oven with manual control, a mechanical timer, dual elements (top and bottom), a minimum power of 1500W, with no LCD or other electronic controls.

If you can get a convection oven that matches these requirements without spending much more money, then do so. Our oven cost around £40. If you feel tempted to spend much more than £60, check yourself, as you might be buying something beyond what is needed.



This is to whet your appetites ready for next month (when we'll assemble the components into the case). Note: this photo was taken *before* the Presspahn safety shield was installed. For your continued health, it must be included!

The thermocouple

Thermocouples are the 'go-to' device for measuring high temperatures. Thermocouples rely on the thermoelectric effect of two dissimilar metals in contact. A K-type thermocouple has wires made of chromel (nickel/chromium) and alumel (nickel/aluminium/manganese and silicon). These are standard and very interchangeable. They work to well over 1000°C, plenty for this application.

A thermocouple amplifier interface module is also needed. It converts the tiny voltages the thermocouple generates to a higher voltage that we can measure with the PIC. It also performs 'cold junction' compensation.

Just as the thermocouple generates a voltage from the dissimilar metal junction at its tip, it also generates a voltage where the chromel and alumel wires join our controller. The thermocouple amplifier has a built-in compensation for this (which depends on its own temperature).

This meant that if you need the ultimate precision, you will need to connect the thermocouple wires straight to the thermocouple amplifier, and not use plugs as shown in our project (Jaycar also has a thermocouple without the plugs, Cat QM1823).

But we think this compromise is acceptable because the error from using the plugs and sockets is small.

Incidentally, the thermocouple amplifier we used has a purple PCB. If you search ebay or AliExpress for 'AD8495', then you should be able to find one which looks like ours. Note though that some of these devices come with the wrong reference voltage; we'll explain later how to fix that if it happens.

We want a board that uses a 1.25V offset for 0°C. If yours is 2.5V instead, it will not work. The simple fix for this is short the AD8495 reference pin (pin 2) to ground (pin 3), effectively making the reference 0V.

The SSR

We used an Altronics S4416A solid state relay, rated at 40A. This is ideal, although a 20A mains-rated SSR would theoretically be sufficient.

The other thing to check for is to make sure that your SSR (like the Altronics one) will work with a 3.0-3.6V control voltage. Our PIC will drive it with a nominal 3.3V DC to switch it on.

The controller

The controller is based the same 32-bit PIC microcontroller board, LCD screen and set of controls that we used previously in a couple of projects.

Namely, these are the *DSP Active Crossover and 8-channel Parametric Equaliser* (January-March 2020); and *Low Distortion DDS Signal Generator* (February 2021).

The controller module is a lot more powerful than needed, but takes advantage of the graphical user interface (GUI) that I already created for those projects, along with other storage and control code. So, it saved a lot of development time, and you at least get a nice user interface.

To this, I added a K-type thermocouple amplifier I bought from ebay for less than £5 including delivery, along with a 40A solid state relay (SSR).

With these few additions, we have ourselves the makings of a pretty capable oven controller.

The CPU board circuit is shown in Fig.2. We won't describe this in great detail, partly because we already described it in the February 2020 issue but mostly because, despite appearances, it's relatively simple. It consists mainly of microcontroller IC11, two crystal oscillator circuits, an EEPROM chip, a simple power supply and a bunch of connectors for routing signals.

The main change is in the firmware, which has been modified to implement the temperature control loop and to provide a real-time display of the temperature profile achieved.

The overall function of the resulting controller is simple. In operation mode, the microcontroller reads the temperature about 10 times a second, and averages this over half a second.

Every half-second, the PID control parameters are updated and the controller decides whether to switch the oven on or off.

See the accompanying panel for a description on how PID temperature control works.

In setup mode, you can save the settings, alter the PID parameters, set the temperatures for heat soak and reflow, or set the thermocouple temperature coefficient and offset.

Fig.3 shows what's on the front panel control board that connects

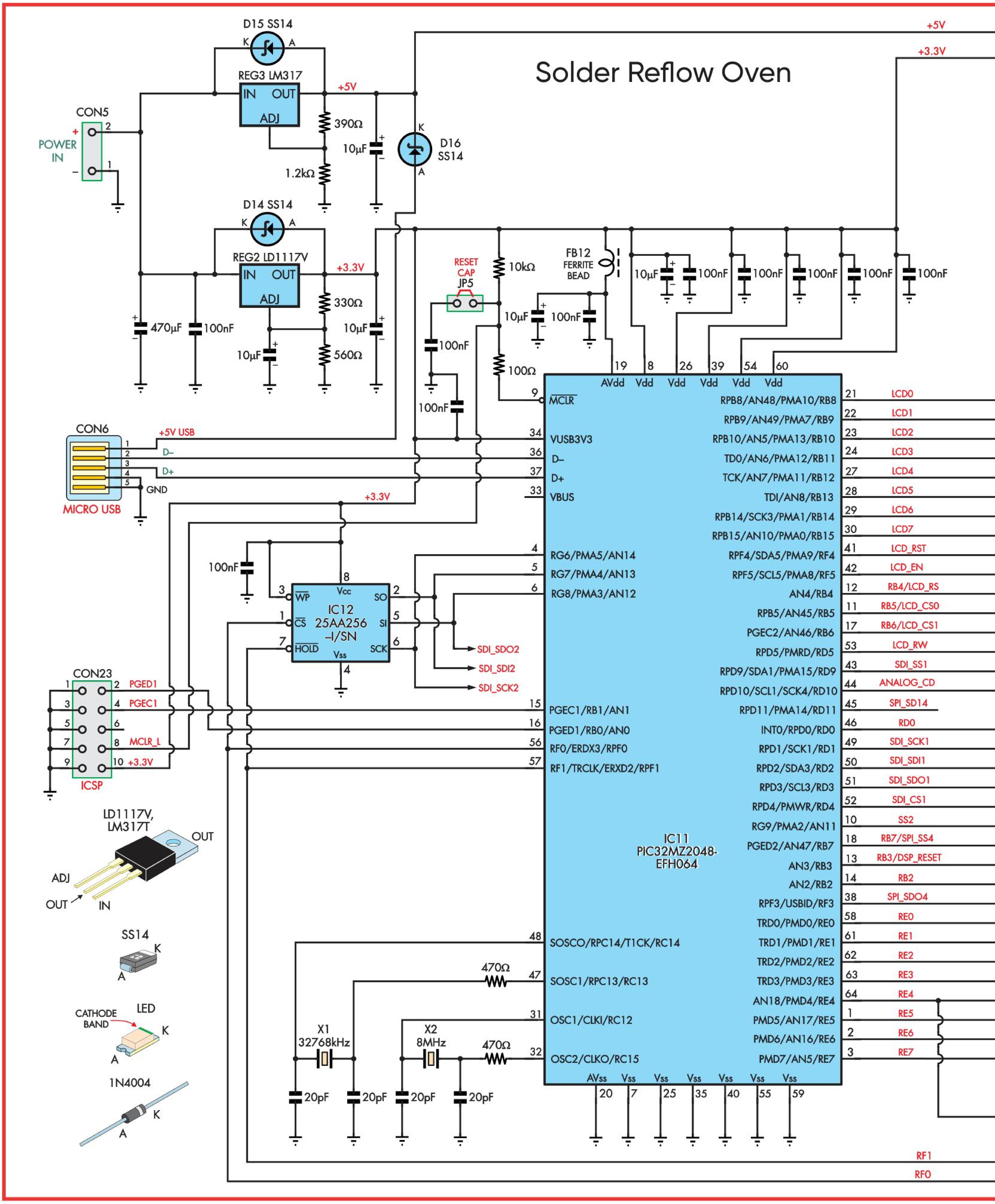
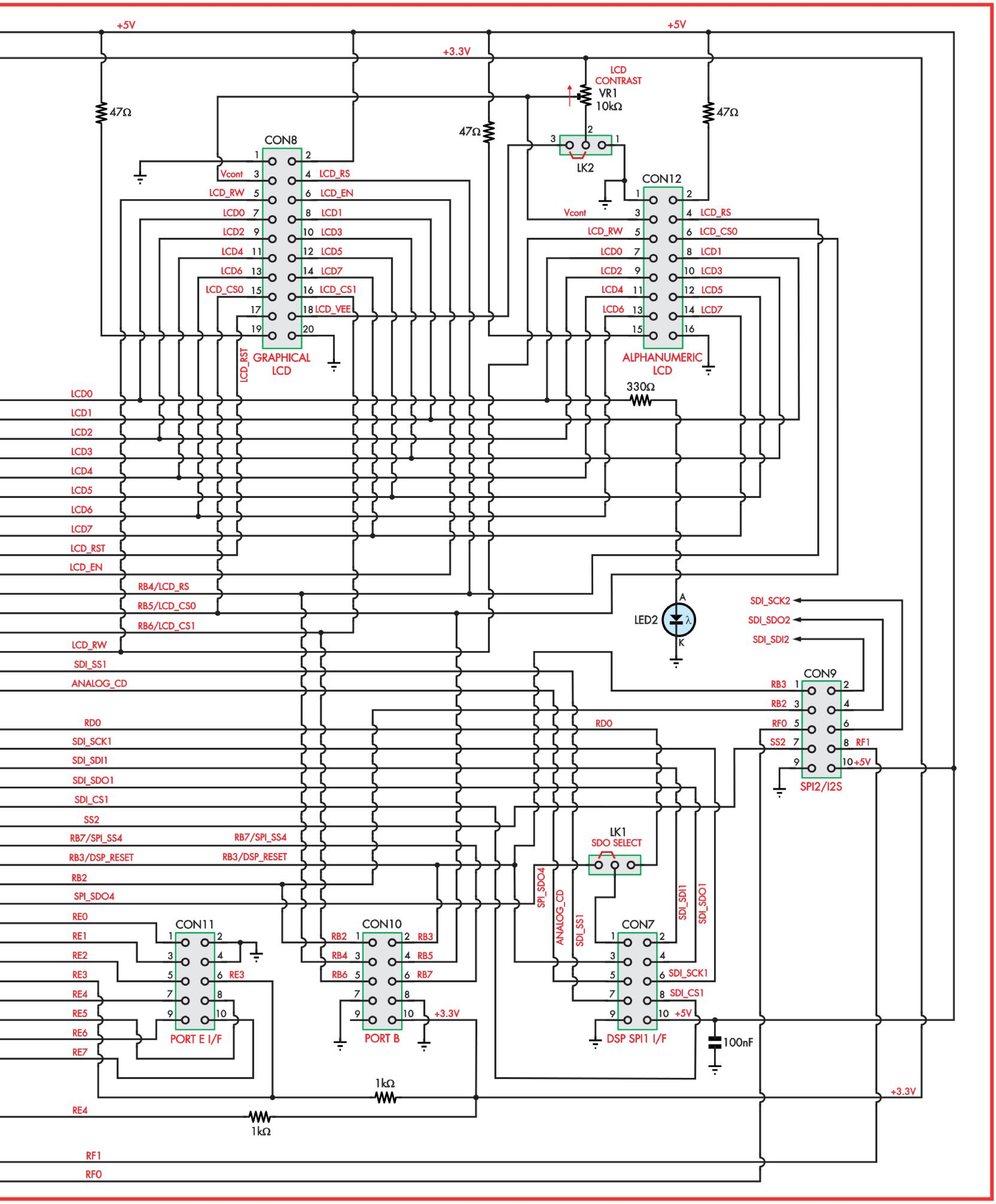

Solder Reflow Oven
+5V
+3.3V
D15 SS14
K
A
REG3 LM317
IN
OUT
ADJ
390Ω
10µF
D16
SS14
1.2kΩ
CON5
POWER
IN
D14 SS14
REG2 LD1117V
+3.3V
330Ω
560Ω
470µF
100nF
10µF
RESET
CAP
JP5
10kΩ
100Ω
FB12
FERRITE
BEAD
CON6
MICRO USB
+5V USB
D–
D+
GND
IC12
25AA256
–I/SN
WP
CS
HOLD
Vcc
Vss
SO
SI
SCK
SDI_SDO2
SDI_SDI2
SDI_SCK2
CON23
ICSP
PGED1
PGEC1
MCLR_L
IC11
PIC32MZ2048-
EFH064
AVdd
Vdd
MCLR
VUSB3V3
VBUS
RG6/PMA5/AN14
RG7/PMA4/AN13
RG8/PMA3/AN12
PGEC1/RB1/AN1
PGED1/RB0/AN0
RF0/ERDX3/RPF0
RF1/TRCLK/ERXD2/RPF1
SOSCO/RPC14/T1CK/RC14
SOSCI/RPC13/RC13
OSC1/CLKI/RC12
OSC2/CLKO/RC15
RPB8/AN48/PMA10/RB8
RPB9/AN49/PMA7/RB9
RPB10/AN5/PMA13/RB10
TD0/AN6/PMA12/RB11
TCK/AN7/PMA11/RB12
TDI/AN8/RB13
RPB14/SCK3/PMA1/RB14
RPB15/AN10/PMA0/RB15
RPF4/SDA5/PMA9/RF4
RPF5/SCL5/PMA8/RF5
AN4/RB4
RPB5/AN45/RB5
PGEC2/AN46/RB6
RPD5/PMRD/RD5
RPD9/SDA1/PMA15/RD9
RPD10/SCL1/SCK4/RD10
RPD11/PMA14/RD11
INT0/RPD0/RD0
RPD1/SCK1/RD1
RPD2/SDA3/RD2
RPD3/SCL3/RD3
RPD4/PMWR/RD4
RG9/PMA2/AN11
PGED2/AN47/RB7
AN3/RB3
AN2/RB2
RPF3/USBID/RF3
TRD0/PMD0/RE0
TRD1/PMD1/RE1
TRD2/PMD2/RE2
TRD3/PMD3/RE3
AN18/PMD4/RE4
PMD5/AN17/RE5
PMD6/AN16/RE6
PMD7/AN5/RE7
AVss
Vss
LCD0
LCD1
LCD2
LCD3
LCD4
LCD5
LCD6
LCD7
LCD_RST
LCD_EN
RB4/LCD_RS
RB5/LCD_CS0
RB6/LCD_CS1
LCD_RW
SDI_SS1
ANALOG_CD
SPI_SD14
RD0
SDI_SCK1
SDI_SDI1
SDI_SDO1
SDI_CS1
SS2
RB7/SPI_SS4
RB3/DSP_RESET
RB2
SPI_SDO4
RE0
RE1
RE2
RE3
RE4
RE5
RE6
RE7
RF1
RF0
X1
32768kHz
X2
8MHz
470Ω
20pF
LD1117V,
LM317T
OUT
ADJ
IN
SS14
LED
CATHODE
BAND
1N4004

Fig.2: the circuit of the control board. 32-bit microcontroller IC11 derives its internal clock from 8MHz crystal X2 and has numerous supply bypass capacitors. It runs from a regulated 3.3V supply provided by adjustable low-dropout regulator REG2. EEPROM IC12 is used to store the settings (eg, PID parameters, temperatures settings). The graphical LCD is connected via CON8, the front panel controls via CON11 and the thermocouple and SSR via CON10.

to the CPU board via a ribbon cable. Rotary encoder RE1 (with integral switch) and switch S1 allow the user to step through menus, select options and alter values.

Switch S2 is only needed if an encoder is used without an internal switch. The capacitors are for debouncing while the resistors, two of which are omitted, tell the CPU what type of encoder was used.


+5V
+3.3V
+5V
LCD CONTRAST
VR1 10kΩ
47Ω
47Ω
47Ω
CON8
Vcont
LCD_RW
LCD0
LCD2
LCD4
LCD6
LCD_CS0
LCD_RS
LCD_EN
LCD1
LCD3
LCD5
LCD7
LCD_CS1
LCD_VEE
LCD_RST
GRAPHICAL LCD
LK2
CON12
Vcont
LCD_RW
LCD0
LCD2
LCD4
LCD6
LCD_RS
LCD_CS0
LCD1
LCD3
LCD5
LCD7
ALPHANUMERIC LCD
330Ω
LCD0
LCD1
LCD2
LCD3
LCD4
LCD5
LCD6
LCD7
LCD_RST
LCD_EN
RB4/LCD_RS
RB5/LCD_CS0
RB6/LCD_CS1
LCD_RW
SDI_SS1
ANALOG_CD
RD0
SDI_SCK1
SDI_SDI1
SDI_SDO1
SDI_CS1
SS2
RB7/SPI_SS4
RB3/DSP_RESET
RB2
SPI_SDO4
RE0
RE1
RE2
RE3
RE4
RE5
RE6
RE7
RE4
RF1
RF0
LED2
A
K
SDI_SCK2
SDI_SDO2
SDI_SDI2
CON9
RB3
RB2
RF0
SS2
RF1
+5V
SPI2/I2S
RD0
LK1
SDO SELECT
SPI_SDO4
ANALOG_CD
SDI_SS1
SDI_SDI1
SDI_SDO1
CON7
SDI_SCK1
SDI_CS1
+5V
DSP SPI1 I/F
100nF
CON11
RE3
PORT E I/F
CON10
RB2
RB4
RB6
RB3
RB5
RB7
+3.3V
PORT B
1kΩ
1kΩ
+3.3V

Construction

The first job is to assemble the PIC32 microcontroller module. Its PCB overlay diagram is shown in Fig.4. Use this as a guide to which parts go where on the 60.5 × 62.5mm PCB, which is coded 01106193.

Start with IC11, the 64-pin SMD microcontroller (it sure would be handy to have a reflow oven at this stage, wouldn't it!). Make very sure that it is oriented correctly before soldering its leads.

The required HEX file (2910420A.HEX) is available for download from the April 2021 page of the website.

You program the PIC using a PICKit 3 programmer once the board has been assembled (see Fig.10 for the slightly unusual wiring required).

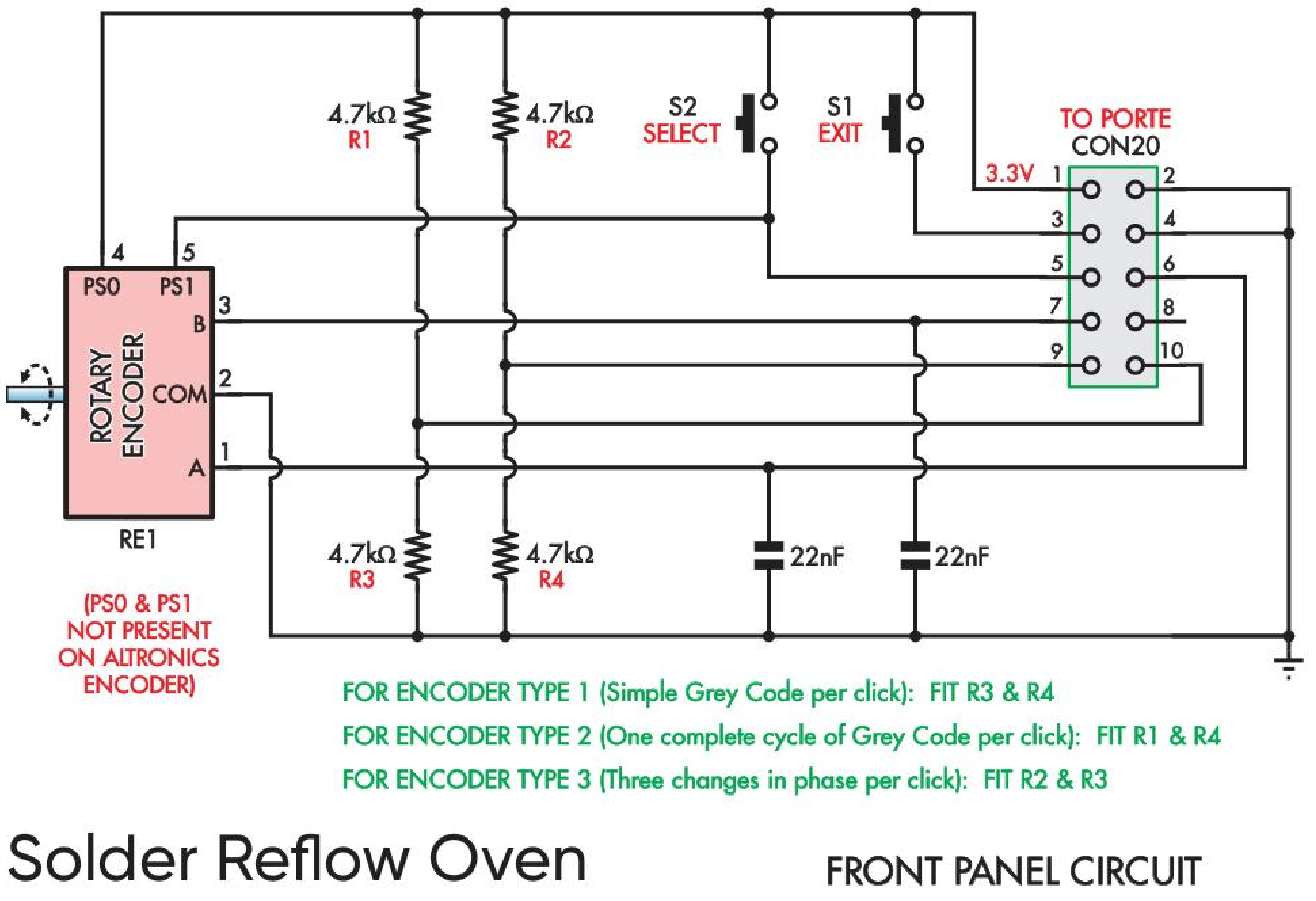

4.7kΩ
R1
4.7kΩ
R2
S2
SELECT
S1
EXIT
TO PORTE
CON20
3.3V
1
2
3
4
5
6
7
8
9
10
4
5
PS0
PS1
B
3
ROTARY ENCODER
COM
2
A
1
RE1
4.7kΩ
R3
4.7kΩ
R4
22nF
22nF
(PS0 & PS1 NOT PRESENT ON ALTRONICS ENCODER)
FOR ENCODER TYPE 1 (Simple Grey Code per click): FIT R3 & R4
FOR ENCODER TYPE 2 (One complete cycle of Grey Code per click): FIT R1 & R4
FOR ENCODER TYPE 3 (Three changes in phase per click): FIT R2 & R3
Solder Reflow Oven
FRONT PANEL CIRCUIT

Fig.3: the components shown here mount on a front-panel board that allows you to control the unit. Rotary encoder RE1 and pushbutton S1 connect back to the control module via CON20. S2 is only required if you use a rotary encoder without an internal switch. The capacitors debounce the rotary encoder signals.

Tack down a couple of pins and make sure that all of its pins are correctly located over their pads before applying flux paste and soldering the rest. Solder bridges are almost inevitable if hand-soldering, but these can be cleaned up with the application of more flux paste and some solder wick. Follow with the other SMDs, making sure that IC12 and the diodes are oriented correctly. (You don't need to fit CON6 for this project.)

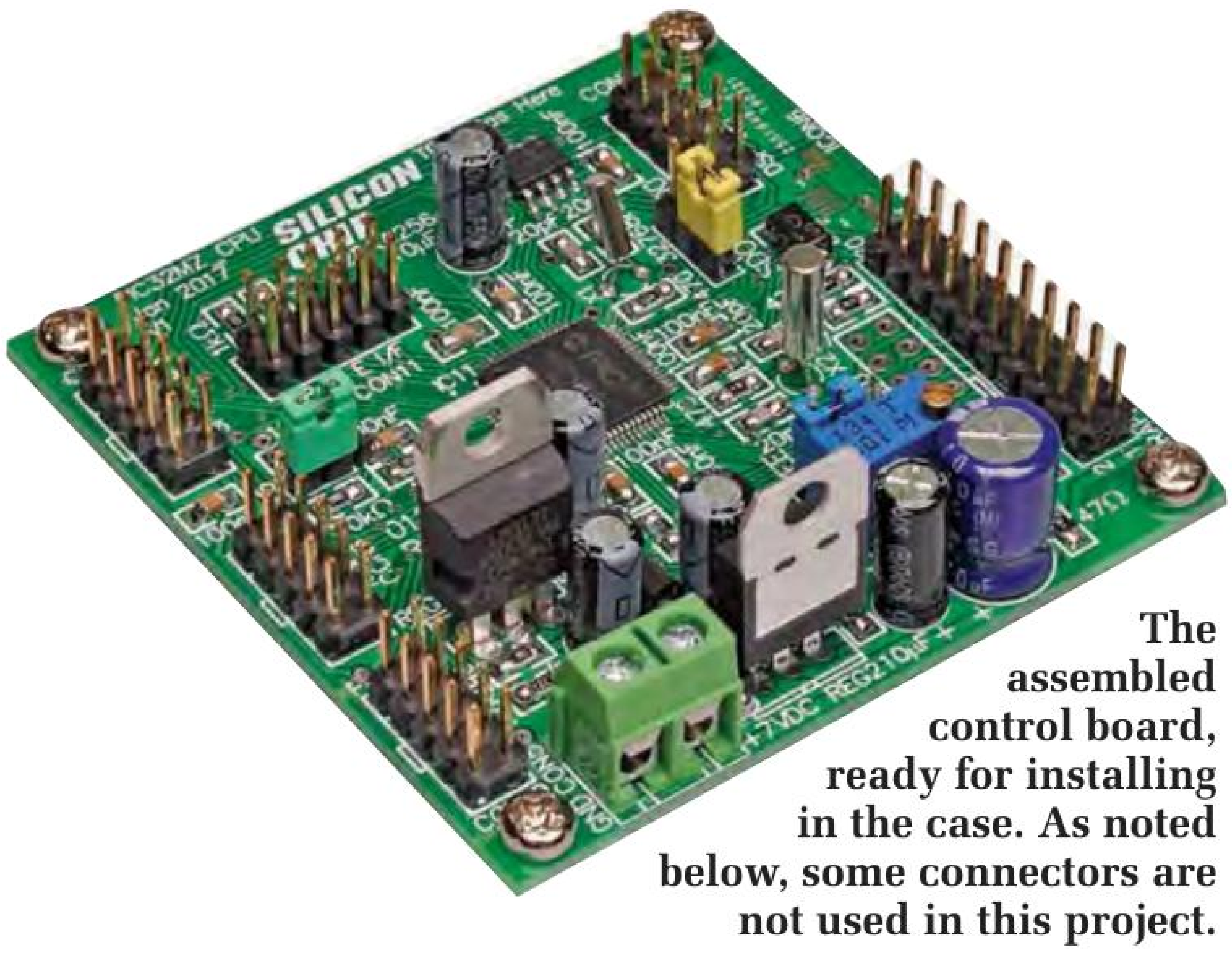
Next, fit the through-hole components; don't get REG2 and REG3 mixed up and note that REG2 now has a small flag heatsink fitted. When mounting X2, if there is any chance of the bottom of its metal package shorting to components below, fit an insulating washer underneath. CON12 can be left off.

You can now move onto building the front panel control board. Its overlay diagram is shown in Fig.5. The PCB is coded 01106195 and measures 107.5 × 32.5mm.

There isn't a lot to assembling it; if you're using the recommended Jaycar SR1230 rotary encoder, besides that part, you just need one pushbutton (S1), two capacitors, two resistors (R2 and R3) and header CON20. The capacitors and CON20 are mounted on the underside, with the caps laid over.

We bought our K-type thermocouple on ebay for just over a pound – including postage!

N2K3
11402058
made in china

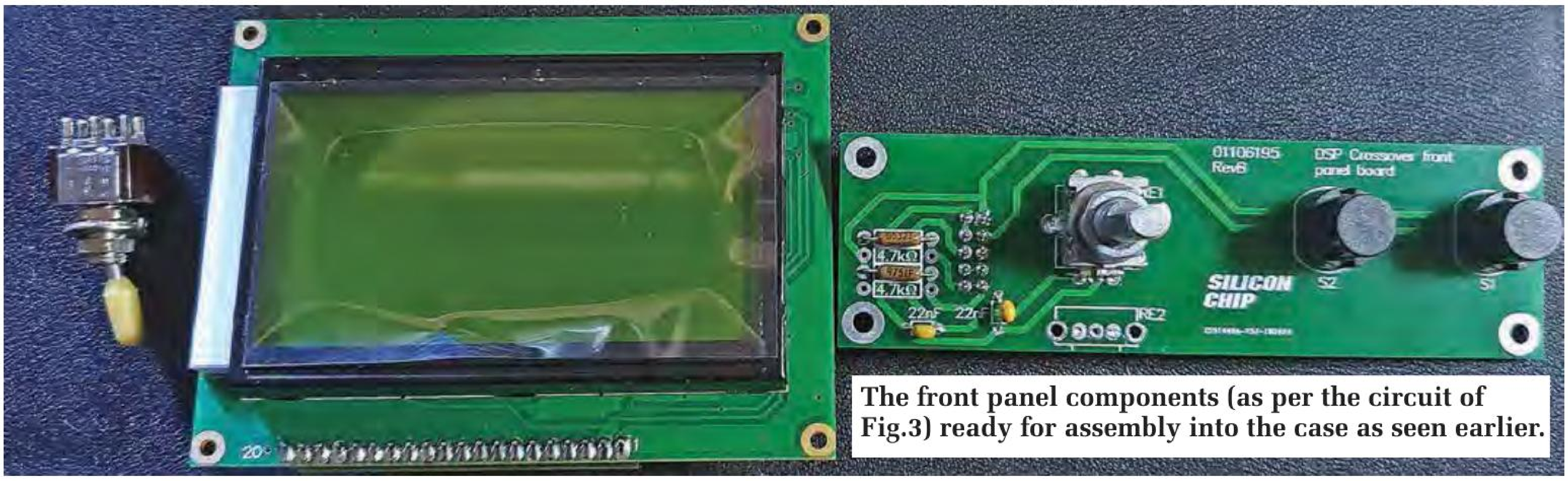


The assembled control board, ready for installing in the case. As noted below, some connectors are not used in this project.

Now is also a good time to solder the two headers to the small board coded 01106196 which measures 51 × 13mm, shown in Fig.6. The SIL header goes on one side and the DIL header on the other. Then solder its SIL header to the LCD module, with this board mounted on the back.

Next, make up the two ribbon cables. One has 20 wires, and one has 10 wires. They are the same length; see Fig.7 for details. Cut each section of the ribbon cable to length, leaving around 5cm extra in each case for crimping to the connectors.

You can strip these cables out of ribbon cables with more wires, by making a small cut between two wires and then separating the sections by pulling them apart.


01106195
RevB
DSP Crossover front panel board
RE1
4.7kΩ
4.7kΩ
22nF
22nF
SILICON CHIP
S2
S1
RE2

The front panel components (as per the circuit of Fig.3) ready for assembly into the case as seen earlier.

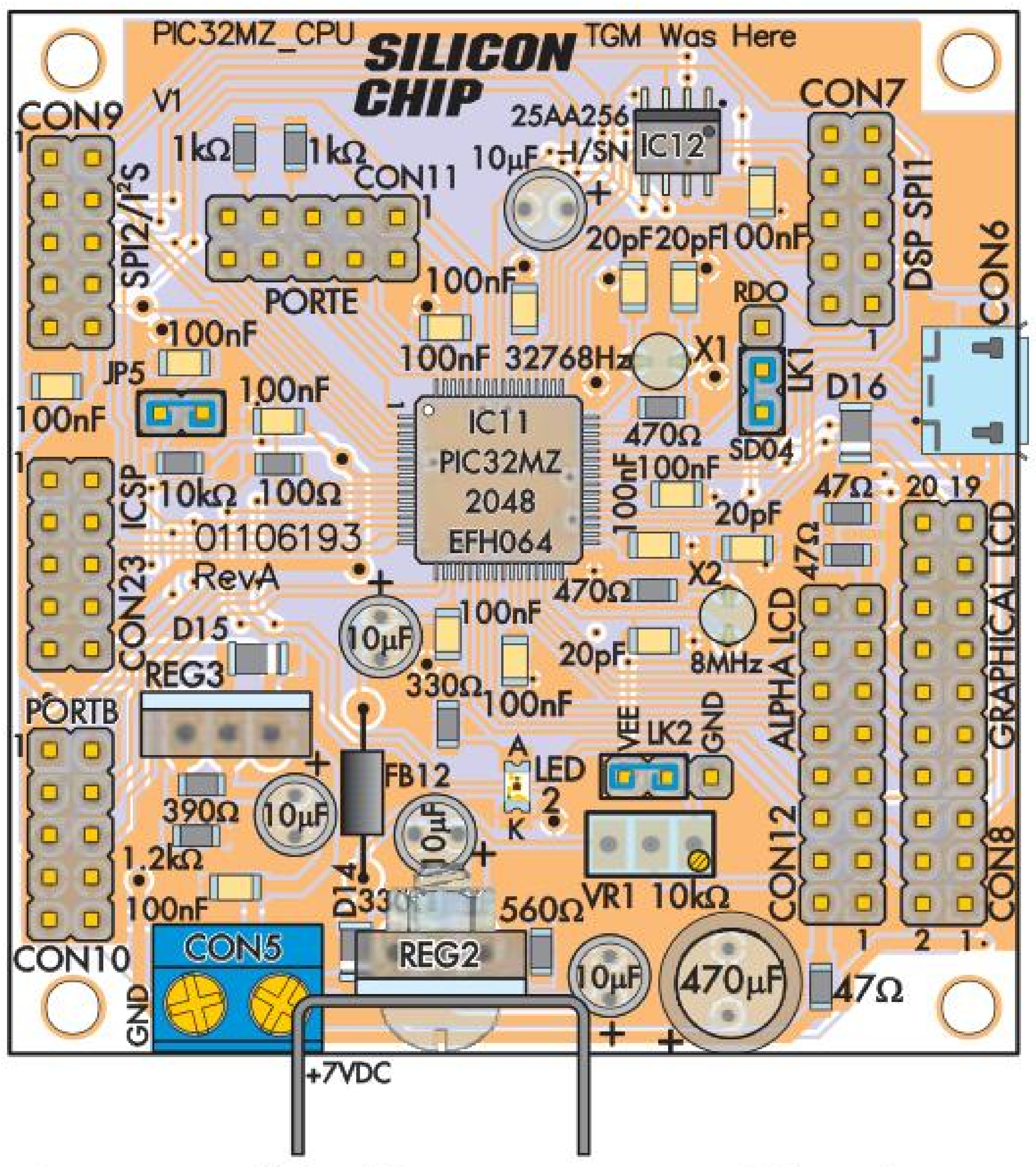

PIC32MZ_CPU
SILICON CHIP
TGM Was Here
CON9
V1
1kΩ
1kΩ
CON11
25AA256
-I/SN
IC12
10µF
CON7
SPI2/I²S
PORTE
100nF
20pF
20pF
100nF
DSP SPI1
CON6
RDO
LK1
100nF
32768Hz
X1
JP5
100nF
100nF
D16
IC11
PIC32MZ
2048
EFH064
470Ω
SD04
100nF
ICSP
10kΩ
100Ω
01106193
RevA
47Ω
20
19
20pF
47Ω
CON23
D15
REG3
10µF
100nF
470Ω
X2
8MHz
20pF
330Ω
ALPHA LCD
GRAPHICAL LCD
PORTB
390Ω
10µF
FB12
A
LED 2
K
VEE
LK2
GND
1.2kΩ
100nF
D14
330Ω
560Ω
VR1 10kΩ
CON12
CON8
CON10
CON5
REG2
10µF
470µF
47Ω
GND
+7VDC

Fig.4: use this diagram as a guide when assembling the control board. It's easiest to fit the SMDs first, starting with the ICs. Watch the orientation of the ICs, diodes, electrolytic capacitors and regulators. Some components are not required for this application, including CON6, CON7, CON9 and CON12.

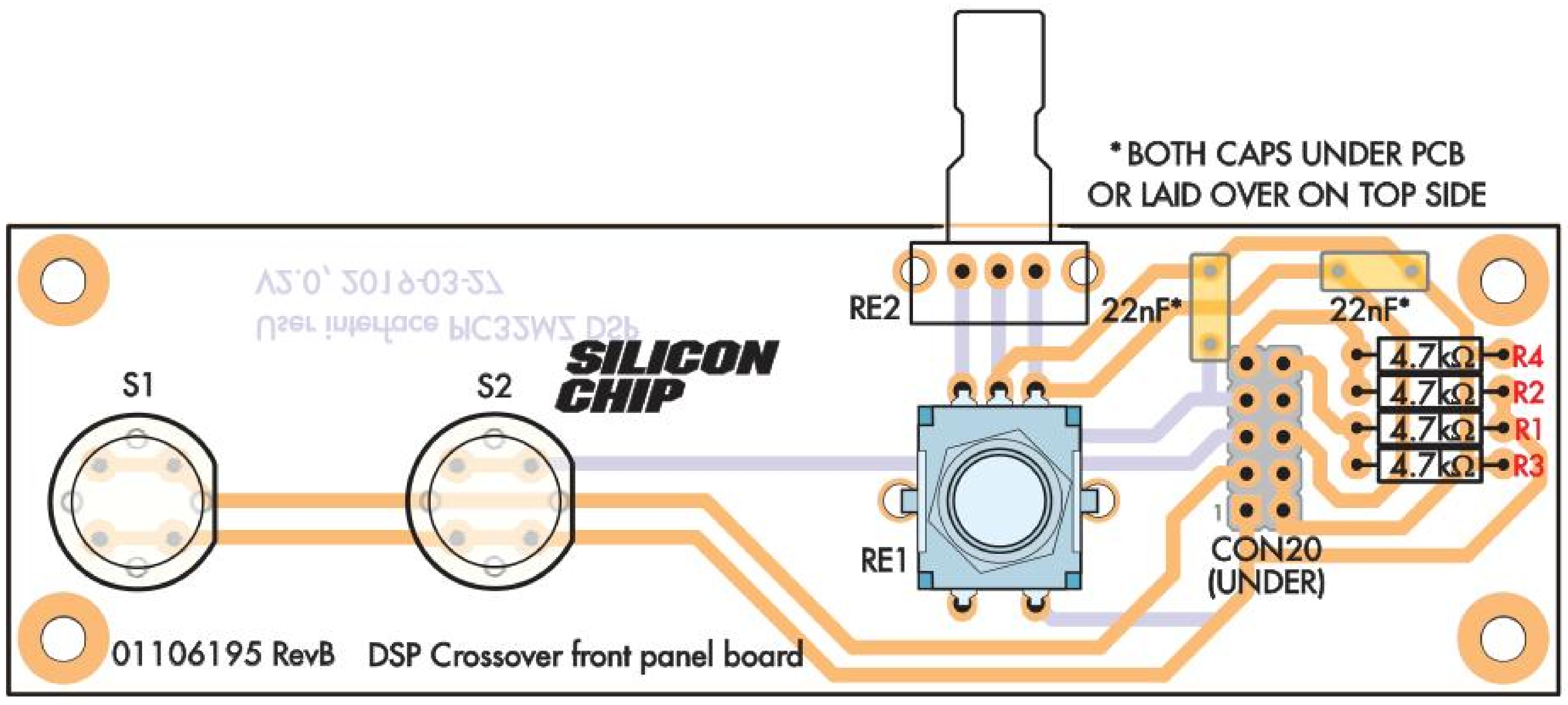
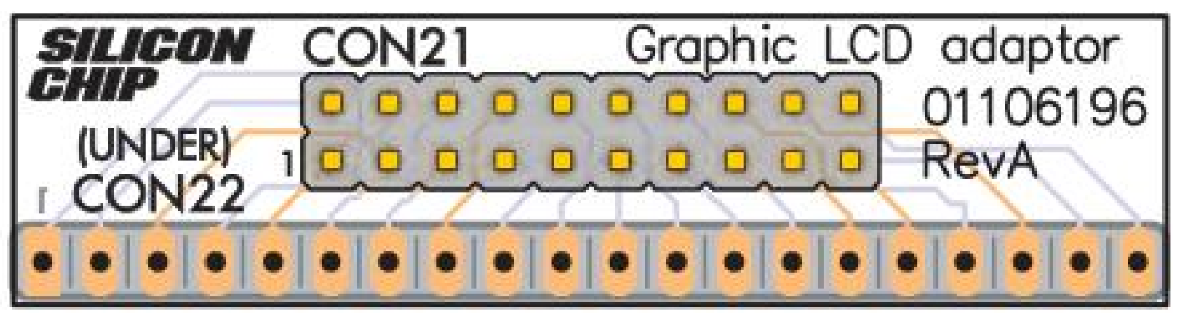

*BOTH CAPS UNDER PCB
OR LAID OVER ON TOP SIDE
RE2
22nF*
22nF*
SILICON CHIP
S1
S2
4.7kΩ
4.7kΩ
4.7kΩ
4.7kΩ
R4
R2
R1
R3
RE1
CON20
(UNDER)
01106195 RevB DSP Crossover front panel board

Fig.5: the front panel PCB. Note that only one of RE1 (Jaycar SR1230) or RE2 (Altronics S3350) is fitted and in the case where RE1 is used, pushbutton S2 is redundant and may be left off. Also, if RE1 is fitted, fit resistors R2 and R3; if RE2 is fitted, fit resistors R1 and R4.

Fig.6: this small adaptor board converts the SIL header on the LCD screen to a DIL header for connecting to an IDC ribbon cable. The connectors are mounted on opposite sides; make sure the pin 1 connection at both ends is at the same end, as shown.


SILICON CHIP
CON21
Graphic LCD adaptor
01106196
RevA
(UNDER)
CON22
1
1

It's best to use a dedicated IDC crimping tool for this job, such as Altronics T1540. You can use a vice, but you have to be careful to avoid crushing and breaking the plastic IDC connectors.

Each connector has three parts: the bottom part, which has the metal blades that cut into the ribbon cable; the middle part, which clamps the cable down onto these; and a locking bar at the top that holds it all together once it has been crimped.

Note how, as shown in Fig.7, the cable passes between the locking bar and upper part before folding over on the outside edge and then being crimped underneath.

So with this in mind, slightly separate the three pieces without actually taking them apart, and feed the ribbon cable through as shown.

Ensure there is enough 'meat' for the metal blades to cut into, then place it into your crimping tool or vice without allowing the cable to fall out.

Clamp the three pieces together, gently at first, then more firmly. The trick is to crimp it hard enough to ensure that the blades cut fully through the insulation and make good contact with the copper wires, without pressing so hard that you break the plastic.

If using a vice, it's best to wedge a piece of cardboard between each end of the connector and the vice, to provide some cushioning.

Once you've crimped a connector at one end of the cable, do the one at the other end, making sure that when you're finished, the locating spigots will both be facing in the same direction.

In the second and final part of this project, which will appear in our May issue, we'll cover the steps involved in putting the controller in a case and safely checking that all is operating correctly.

We'll also have a list of troubleshooting suggestions in the unlikely even that you cannot get your controller to... control!

In the meantime, you can gather all the components, PCBs and everything else you need.

Don't forget the oven!

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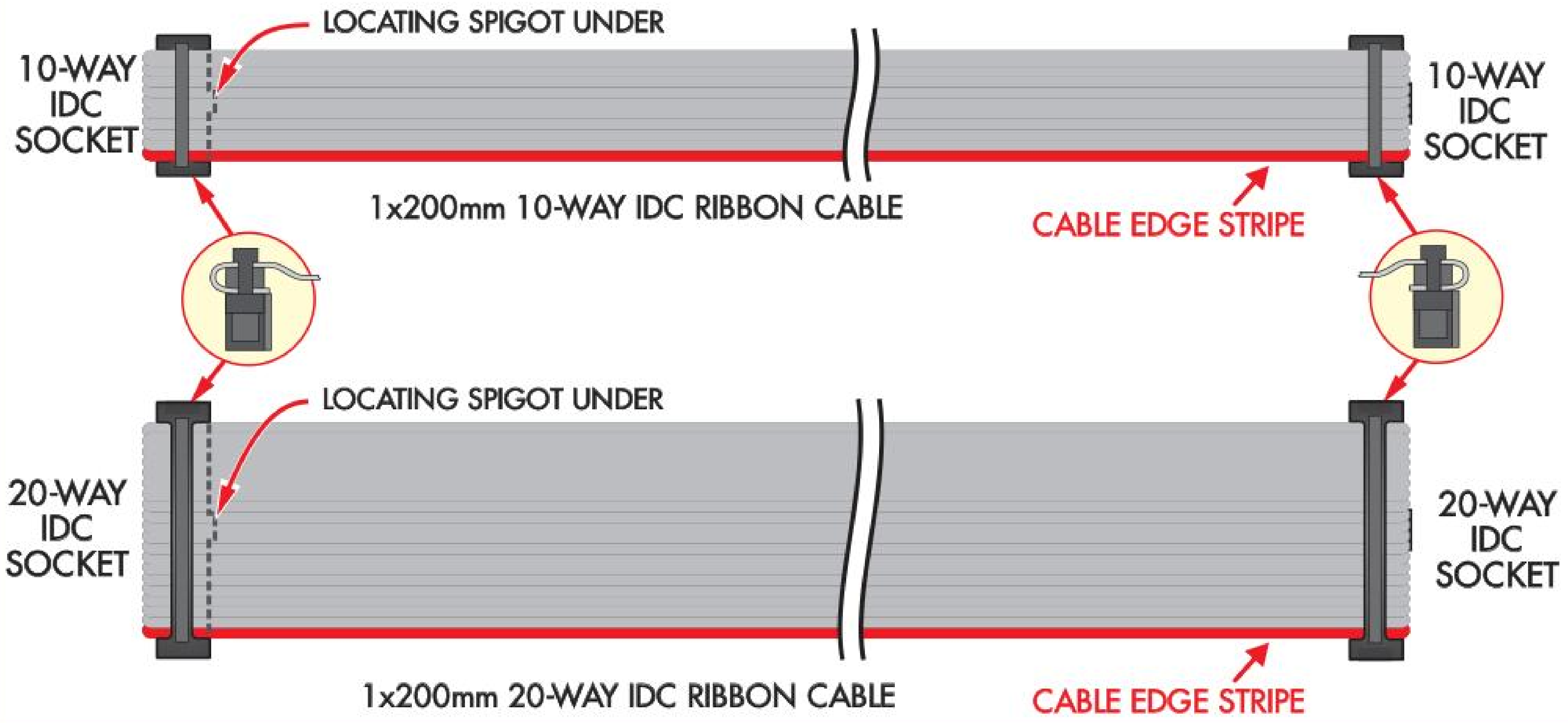
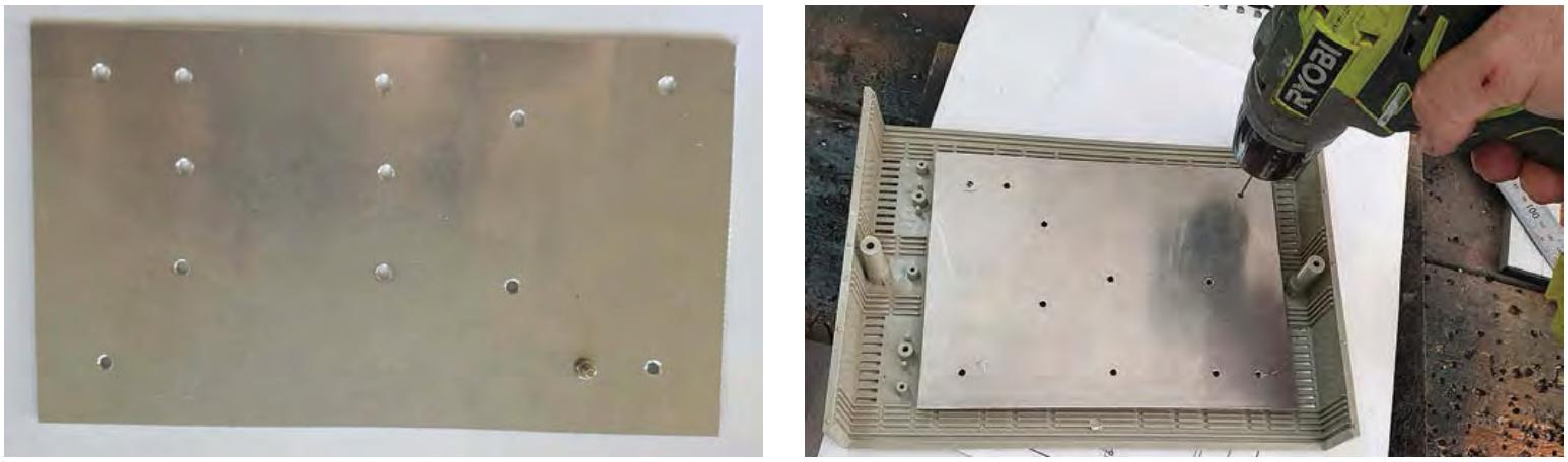

10-WAY IDC SOCKET
LOCATING SPIGOT UNDER
10-WAY IDC SOCKET
1x200mm 10-WAY IDC RIBBON CABLE
CABLE EDGE STRIPE
LOCATING SPIGOT UNDER
20-WAY IDC SOCKET
20-WAY IDC SOCKET
1x200mm 20-WAY IDC RIBBON CABLE
CABLE EDGE STRIPE

Fig.7: you need to make two ribbon cables: one to connect the front panel to the CPU board, and the other to connect the LCD. Note the orientation of the connector tabs, so that pin 1 is aligned with the red stripe at both ends. Make sure the IDC blades are pressed down hard enough to fully pierce the insulation and make good contact, but not so hard that you crack the plastic!



Dimensioned diagrams for drilling this plate, the front and rear panels and drilling/cutting the Presspahn safety shield can all be downloaded from the April 2021 page of the *PE* website.

Parts list – Reflow Oven Conversion

1 260 x 190 x 80mm plastic instrument case [Altronics H0482]
1 200 x 115mm sheet of 1.5mm-thick aluminium
1 205 x 185mm sheet of Presspahn or similar [Jaycar HG9985]
1 K-type thermocouple with banana plugs [Jaycar QM1284]
1 AD8495-based K-type thermocouple interface with purple PCB [eBay/AliExpress]
1 populated PIC32MZ CPU board – see below
1 populated front panel control board – see below
1 128 x 64 pixel graphical LCD with 20-pin connector
1 10A dual (male/female) chassis-mount IEC power connector [Altronics P8330A]
1 9V DC 2/3A regulated plugpack with 2.1mm inner diameter plug [Altronics M8923]
1 2.1mm inner diameter chassis-mount barrel socket [Altronics P0628]
1 red binding post/banana socket [Altronics P9252, Jaycar PT0453]
1 black binding post/banana socket [Altronics P9254, Jaycar PT0454]
1 double-sided PCB, coded 01106196, 51 x 13mm
1 40A 24-240VAC solid-state relay (SSR1) [eg, Altronics S4416A]
1 SPST, SPDT or DPDT 12V DC, 1A toggle switch (main power switch)
1 IEC C14 male to 3-pin mains socket [Jaycar PS4100]
1 IEC mains power cable [Jaycar PS4106]
1 15x2 pin header
1 20-pin header
2 20-pin IDC line plugs
3 10-pin IDC line plugs
1 small tube of neutral-cure silicone sealant
1 small tube of heatsink (thermal) paste

Cables and hardware

4 M3-tapped 15mm nylon standoffs
8 M3-tapped 10mm nylon standoffs
25 M3 x 15mm panhead machine screws
25 M3 x 6mm panhead machine screws
25 M3 star/lock washers
10 M3 hex nuts
8 5mm red eyelet crimp connectors [Altronics H2041A]
1 20cm length of three-core 10A mains flex
1 50cm length of red light-duty hookup wire
1 30cm length of black light-duty hookup wire
1 30cm length of green light-duty hookup wire
1 25cm length of 20-way ribbon cable
2 25cm lengths of 10-way ribbon cable
1 6cm length of 40-50mm diameter clear heatshrink tubing
1 50cm length of 10mm diameter clear heatshrink tubing
1 30cm length of 8mm diameter clear heatshrink tubing
cable ties as required

PIC32MZ CPU board parts

1 double-sided PCB coded 01106193, 60.5 x 62.5mm
1 2-way mini terminal block, 5.08mm spacing (CON5)
5 5x2 pin headers (CON7,CON9-CON11,CON23)
1 10x2 pin header (CON8)
2 3-pin headers (LK1,LK2)
1 2-pin header (JP5)
3 shorting blocks (LK1,LK2,JP5)
1 ferrite bead (FB12)
1 32768Hz watch crystal (X1)
1 miniature 8MHz crystal (X2) ***OR***
1 standard 8MHz crystal with insulating washer (X2)
1 10kΩ vertical trimpot (VR1)
1 TO-220 flag heatsink (for REG2) [Altronics H0630]

Semiconductors

1 PIC32MZ2048EFH064-250I/PT 32-bit microcontroller programmed with 2910420A.HEX, TQFP-64 (IC11)
1 25AA256-I/SN 32KB I^{2}C EEPROM, SOIC-8 (IC12)
1 LD1117V adjustable 800mA LDO regulator, TO-220 (REG2)
1 LM317T adjustable 1A regulator, TO-220 (REG3)
1 blue SMD LED, SMA or SMB (LED2)
3 LL5819 SMD 1A 40V schottky diodes, MELF (MLB) (D14-D16)

Capacitors

1 470µF 10V electrolytic
5 10µF 50V electrolytic
11 100nF SMD 2012/0805 50V X7R
4 20pF SMD 2012/0805 50V C0G/NP0

Resistors (all SMD 2012/0805 1%)

1 10kΩ 1 1.2kΩ 2 1kΩ 2 470Ω 1 560Ω
1 390Ω 2 330Ω 1 100Ω 3 47Ω

Front panel control board parts

1 double-sided PCB coded 01106195, 107.5 x 32.5mm
1 5x2 pin header (CON20)
2 4.7kΩ 1/4W through-hole resistors
2 22nF through-hole ceramic capacitors
2 PCB-mount snap-action momentary pushbuttons (S1,S2)* [Jaycar SP0721, Altronics S1096]
1 3-pin rotary encoder (RE1/RE2) [eg, Altronics S3350 or Jaycar SR1230 with integrated pushbutton]
1 knob (to suit RE1/RE2)

** only one required if using Jaycar SR1230 encoder*

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Last month we told you what it does and how it works. Now we put it all together and start hatching chickens!

Part II – by Tim Blythman and Nicholas Vinen

PROGRAMMABLE THERMAL REGULATOR

In our March issue, we introduced this versatile Arduino-controlled heating/cooling device. It uses Peltiers to heat or chill water in one or more loops, and it's pretty easy (if a bit involved) to build. It can be used for many tasks, including (but certainly not limited to!) brewing, making cheese and cooking . . . and even hatching chooks! This article has all the instructions describing how to build the two Arduino shields, program the Arduino, build the water loops and tweak it to suit your needs.

Just to prove that this project has many possible uses, here's another one we thought of since last month: it could be used for an egg incubator, to keep bird or reptile eggs warmed to a constant temperature so that they will hatch. That is often done with a heat lamp, but that's wasteful and doesn't take into account varying ambient conditions.

Chicken eggs are ideally kept at 37.5°C until they hatch, and most other bird and reptile eggs are reasonably similar.

By looping some water tubing under the eggs (ideally made from a thermal conductor like copper) and placing a sensor among them, you can set up the *Programable Thermal Regulator* to maintain this ideal temperature.

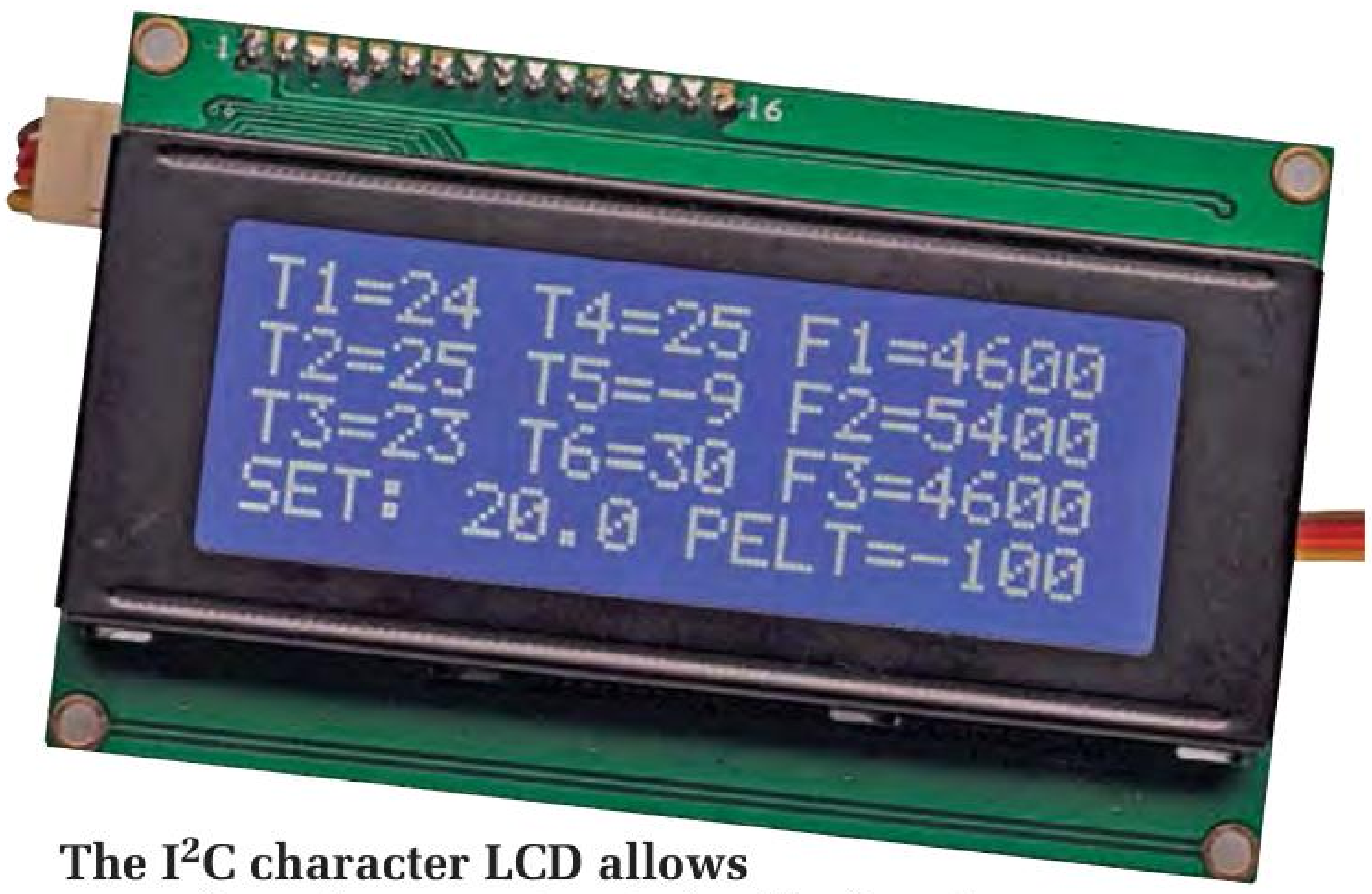
It will only use as much energy as needed to maintain that temperature, and on a sweltering day (which can kill the embryos), it can actually provide a little cooling.

We're sure readers will think of other uses... but enough of that; now it's time to describe how to put it all together, and get it up and running.

Construction

We're going to start by building the two shields, as this is a prerequisite to getting the whole thing up and running. However, if you wish, you can do some basic testing of the 'water circuit' without the control circuitry.

You can rig up the fans, pumps and Peltier devices to run directly from a 12V source to check that everything is working before proceeding.



```
T1=24 T4=25 F1=4600
T2=25 T5=-9 F2=5400
T3=23 T6=30 F3=4600
SET: 20.0 PELT=-100
```

The I²C character LCD allows a number of parameters to be displayed. Temperatures from all six sensors are available, as well as fan speeds, temperature setpoint, mode and Peltier device drive level.

Peltier Driver shield

The Peltier Driver shield uses a mix of surface-mount and through-hole parts; its overlay diagram is shown in Fig.7.

None of the surface-mounted parts are too difficult to solder; the smallest parts are the 3216/1206-size capacitors, which as their name tells you, are relatively large at 3.2 × 1.6mm.

Tweezers, solder flux and solder braid (wick) will be handy – if not mandatory – for working with these parts. Start with those capacitors. They connect to some large copper areas, so may require a fair bit of heat to solder correctly.

Apply a small amount of flux to their pads, then solder one lead of the capacitors in place. If it is square and flat, solder the other lead, otherwise use tweezers and a soldering iron to adjust the first lead before continuing.

The other surface-mounting part is the inductor. As well as connecting to some large copper tracks, it also has a fair amount of thermal mass itself; (if you can) it's time to turn up the iron even higher!

Just as for the capacitors, apply flux (be generous this time), then solder one lead to the PCB. Once the component is in the correct location, solder the other lead. Now is a good time to clean up the excess solder flux using a dedicated flux cleaner or isopropyl alcohol.

Fit the fuse holder parts next, with a fuse temporarily fitted. This ensures that they are spaced and oriented correctly. The fuse can stay in place once they are mounted.

The iron temperature can be reduced for the remaining parts. Continue by fitting diodes D1 and D2 with the cathode stripes oriented as shown, then mount the three resistors. If you aren't sure which is the 1.8kΩ type, measure it with a DMM. Next, fit IC1, ensuring its pin 1 dot/notch goes to the left. We recommend you solder this directly to the board, rather than using a socket.

Now bend the leads of MOSFETs Q1-Q4 to fit the pad pattern and attach each one to the board using a machine screw and nut before soldering and trimming the leads. Make sure the screw is tight before soldering, as tightening it after soldering could damage the solder joints.

Follow with the through-hole capacitors, which are all the same type and not polarised. But make sure you push them fully down before soldering, as there will be another board stacked above this one.

Similarly, push REG1 down as far as you can before soldering it. As mentioned last month, depending on how you will be applying power, you may want to leave REG1 off or link it out (with a wire between its left-most and right-most pads). But in most cases, it is safe to fit it anyway.

The photo top right shows our board as fitted with a link in place of REG1.

The 5x2 header can be soldered now. You can use two 5-way SIL headers side-by-side.

Next, fit CON1 and CON2. Since CON1 sits above the USB socket on the Uno and CON2 above the DC socket, make sure to trim their leads as short as possible after soldering. These are large-leaded parts sitting on copper pours, so they might require the iron temperature to be increased slightly.

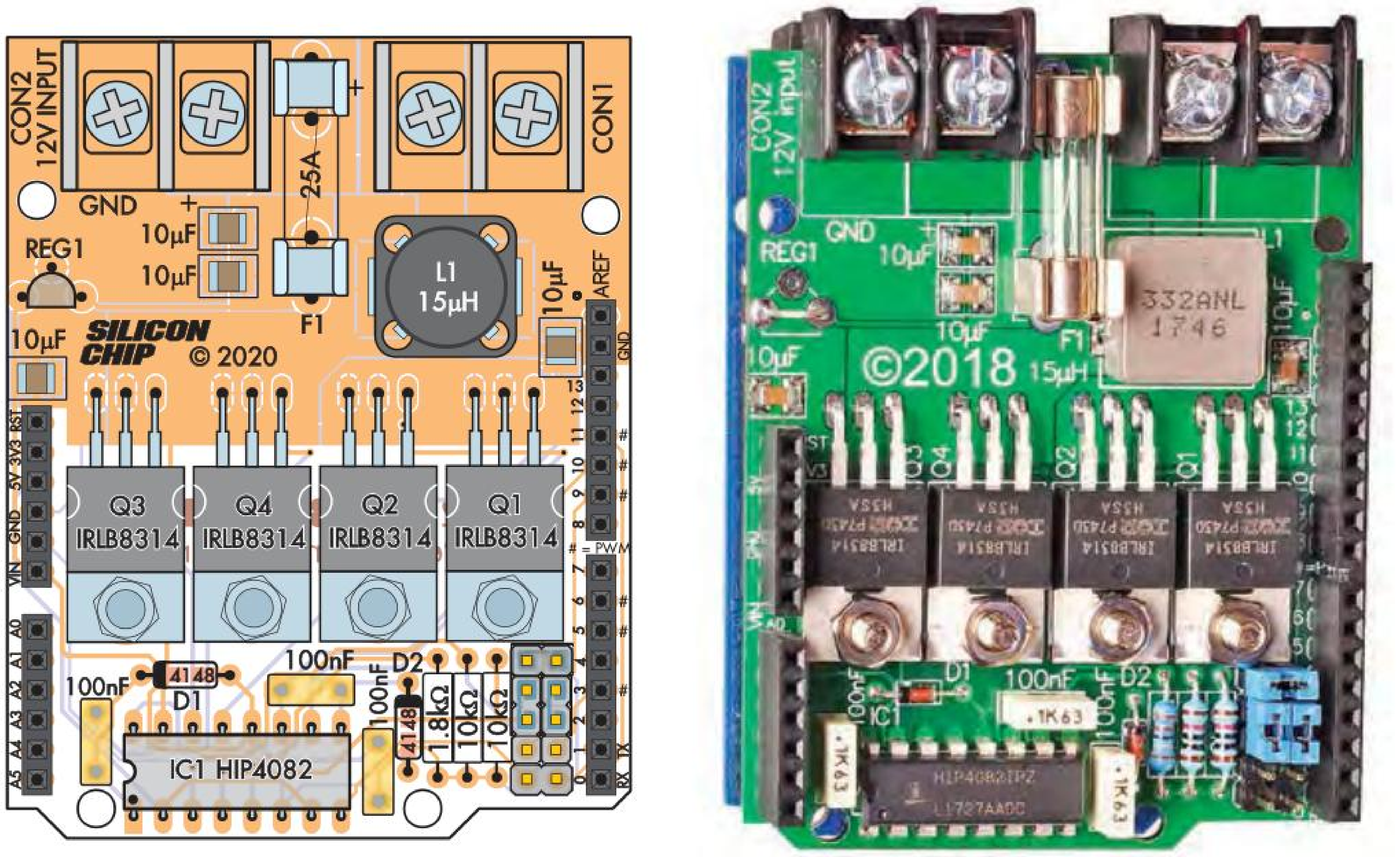


Fig.7: this diagram and photo show where to fit the parts on the Peltier Driver shield. There are five SMDs (four capacitors and one inductor), but they're all quite large. Flux paste will help you solder these; you will need a hot iron to solder the inductor. REG1 is not needed if 12V is being supplied to CON2. In this case, you can install a link across the lower two pads instead.

That just leaves the four stackable headers. We recommend sandwiching the shield between the Uno (underneath) and another shield (above), if you have one. This will help to align the pins. Tack the end pins of each row in place and ensure that all four of them are flat against the PCB at each end. This can be fiddly as moving one can tend to move the others.

Remove the Uno from below and solder the remaining pins before going back and refreshing the end pins of each row.

Jumpers

Insert the three jumpers/shorting blocks, as shown in Fig.7. You shouldn't need to change these unless you are radically changing the software for your own purposes. This sets LK1 to use Arduino pin D10, LK2 to use D9, LK3 closed and LK4 open.

Building the Interface shield

Refer to Fig.8. Start with the resistors. As mentioned earlier, it's best to check each batch with a DMM to verify their value before fitting them. This is especially important as the 100Ω, 1kΩ and 10kΩ types have similar colour bands. Follow with the three diodes, which are all the same type, but ensure they are oriented as shown in Fig.8.

Install the tactile pushbutton (S2) next. Push it down until it clicks and sits flat against the PCB.

There are only two capacitors, both 100nF MKT or ceramic types, one at each end of the board near each IC. Solder these next. Then mount IC1; again, we don't recommend that you use a socket. Ensure that it is fitted with its pin 1 towards CON11. Solder two leads and check that the device is flat; if not, re-heat one of the solder joints and adjust it. Then solder the remaining leads.

Next, install transistors Q1-Q3 and temperature sensor IC2, all of which are in TO-92 packages. Q3 is a different type from Q1 and Q2, so don't get them mixed up. Match the transistor bodies with the silkscreen outlines. You may need to crank their leads out to fit the PCB pads.

Then fit terminal blocks CON10-CON12 and all the polarised headers. Only the orientation of the fan headers is critical; make sure they are rotated as shown in Fig.8 and also ensure that the terminal blocks are mounted with their wire entry holes towards the nearest board edge.

Use a similar technique to the IC when soldering these headers; solder one pin to secure the part, then check it is flat and square before soldering the remaining pins.

Note that we've shown the I^{2}C display header rotated relative to the fan headers; this makes it harder to mix them up as you will damage the display if you accidentally plug it into a fan header and apply power. The two-way headers should all be mounted facing the same way, so that it's easier to rearrange how the temperature sensors are plugged in later.

The three LEDs can be fitted next. The red LED is closest to the edge of the board, green in the middle with the blue LED nearest the switch S1. The cathodes of all three LEDs go towards that switch. Depending on how you are planning on using the finished project, you may wish to attach these via flying leads or even fit pin headers in their place and panel-mount the LEDs.

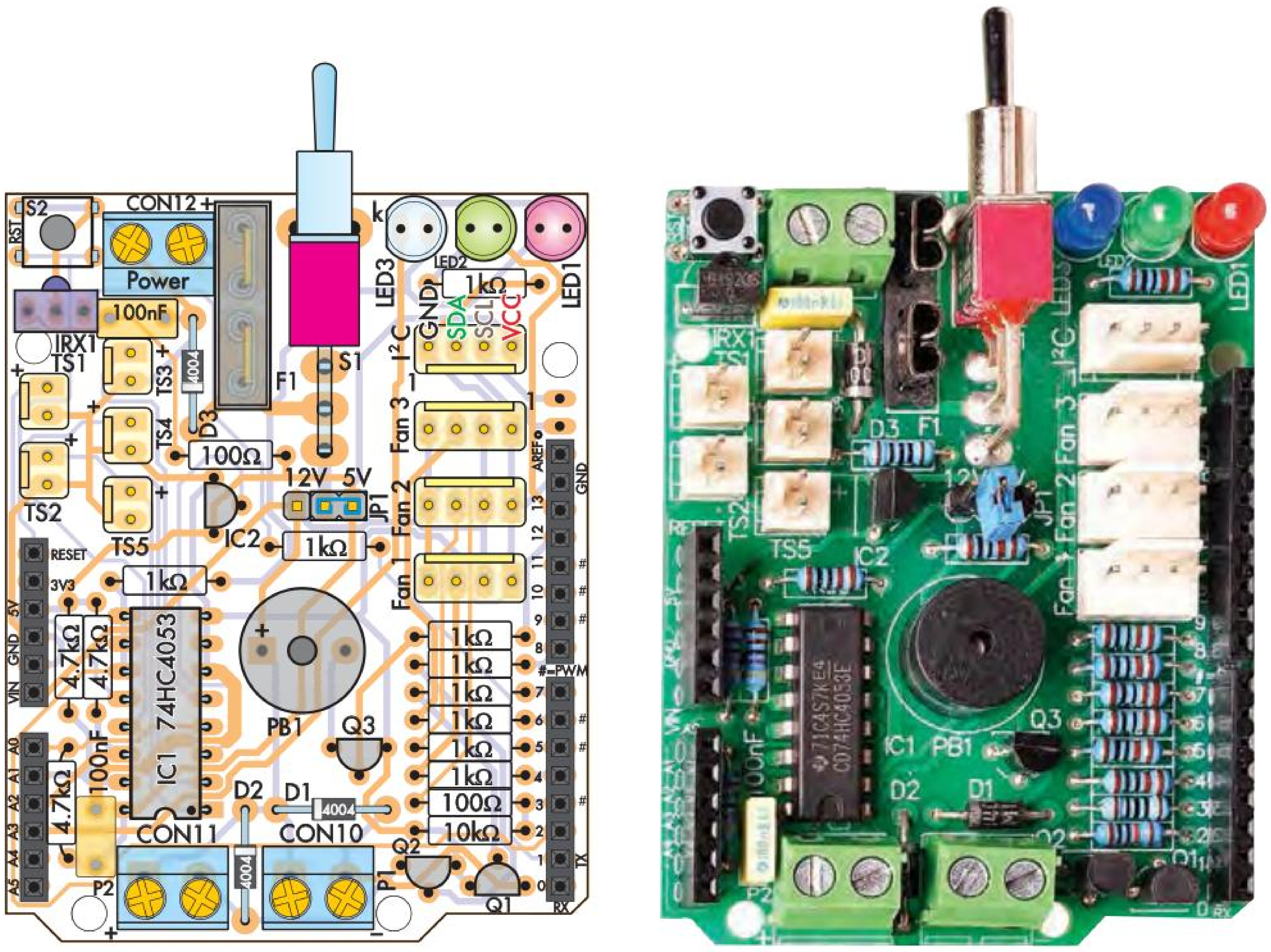


Fig.8: building the Interface shield is straightforward. We recommend that you orient the polarised headers as shown here, but only the fan headers are critical. S1, F1 and JP1 can be omitted if 12V will be supplied from the Peltier Driver shield rather than via CON12. You can use stackable headers along the edges, as shown here, or regular headers fitted on the underside.

A similar comment applies to IRD1; this can also be fitted off-board, although if you're doing that, you'd best keep the leads short if it is to work reliably. Mount this now; if installing it on the board, make sure its hemispherical lens faces in the direction shown on the PCB silkscreen. You can bend it to face upwards, although you'll have to be careful to avoid interfering with the nearby two-pin header.

The piezo buzzer PB1 sits near the centre of the PCB. Check its polarity before fitting it.

If you are planning to power the finished assembly via the Peltier Driver shield, you can leave off switch S1, fuse F1 and jumper JP1. But it doesn't hurt to fit them anyway. If fitting them, try to ensure they are all sitting flat against the PCB. The switch and fuse holder are quite chunky and may require more heat than smaller components.

Completing the Interface shield simply requires fitting the Arduino headers. Standard male headers will be sufficient for most cases, although we fitted stackable headers to our prototype 'just in case', as seen in the photographs. Like the headers for the Peltier Driver shield, you should use other Arduino boards as jigs to ensure the pins are flush and straight.

Assembling the stack

The shields are designed so that the Peltier Driver shield fits between the Arduino Uno at the bottom and the Interface shield on top. The Interface shield must be on top so you can access its various vertical headers.

The simplest way to supply power is to feed it in through the Peltier Driver shield. It will feed modest amounts of 12V power to the boards above and below.

But note that if you are supplying more than 15V to the Peltier Driver shield, REG1 (which is quite small) cannot provide much current to run any pumps or fans connected to the Peltier Interface shield. In this case, it is better to omit REG1 and supply 12V directly to CON12 on the Interface shield.

The power supplied to CON12 on the Interface shield will also power IC1 on the Peltier Driver shield, but this will not draw much.

When assembling the stack, you may find some places where leads or pins touch components on the board below. Trim these if possible; otherwise, insulate with electrical tape. The USB socket of the Uno should have tape placed on its top to protect it from the power connections on the Peltier Driver shield.

If necessary, temporarily disassemble the stack if you need to attach power cables to the Peltier Driver shield.

Preparing the LCD screen

You can purchase the LCD from Jaycar or simply use the type discussed in the June 2018 *PE* article). Either way, you will have to attach the I^{2}C adaptor to the LCD. Line up respective pin 1s on the I^{2}C adaptor module and the LCD board and tack one pin in place. Confirm that the two PCBs are parallel but not touching before soldering the remaining pins.

You will also need to make up a lead to go between the I^{2}C header on the LCD and the I^{2}C header on the Interface shield. We used female-female jumper wires to test our prototype, but these were quite short.

The best option for a permanent setup is to make up a cable with a four-way polarised locking plug at each end. See Fig.8 for the required connections, and check the labels on the LCD I^{2}C adaptor board. As the pins are in a different order (GND, SDA, SCL, VCC on our board and GND, VCC, SDA, SCL on the LCD), some of the wires will have to cross over.

The connection at the Interface shield is keyed while the header supplied with the LCD adaptor is not. You might like to replace the header on the LCD with a keyed type so a reversed connection cannot be made.

Starting to put it all together

At this stage, you need to decide on the exact configuration required for your application(s), if you have not already. Most likely, you will want to build something that looks like one of Fig.3 to Fig.6 in last month's article.

The water paths are critical. Ideally, these should be as short as possible, although if you wish to save on elbows, the tubing can be run in gentle arcs instead of at right-angles.

Remember that you have the option of placing the water connections at the same or opposite ends of the water blocks. We did not test which method would give better results; we suspect the difference will be quite small.

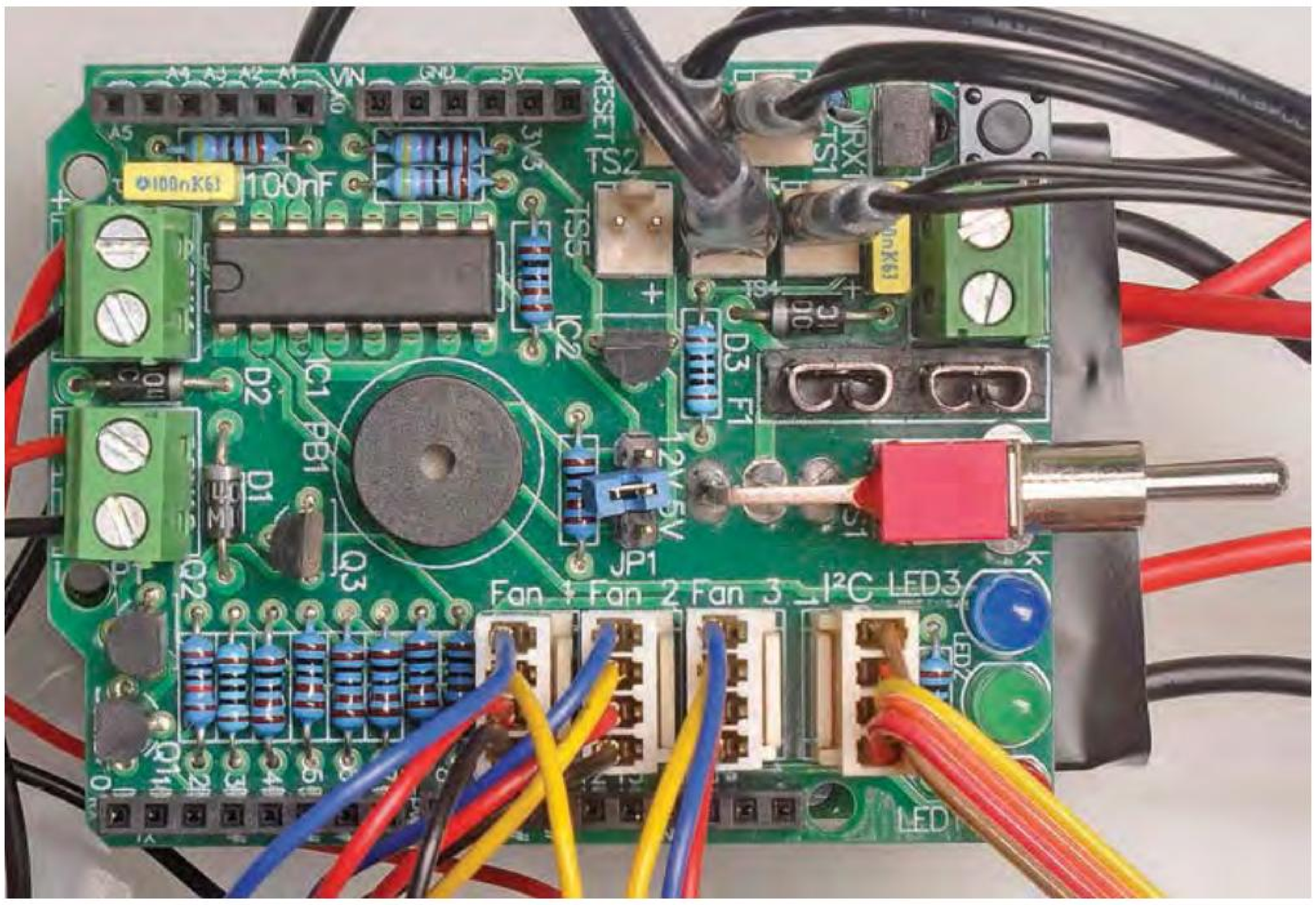
Another point to consider when designing your system is that air from the radiator or heatsink should not blow onto other parts of the assembly, as this will reduce its overall effectiveness.

In our case, we also ensured that the two radiators (one existing on the laser cutter and one on our new boost circuit) blew air in different directions. This can be achieved by placing them next to each other, so that they pull fresh air from the same direction and exhaust in parallel.

Note also our comments last month about insulation. For running a water bath near ambient temperature for cheesemaking or brewing, the demand will not be too high on the Peltier devices, but sous-vide cooking around 60°C or higher will require decent insulation to be able to reach the more extreme temperature targets. If you struggle to reach your temperature target, improved insulation may help.

Peltier device mounting

Our kit came with some hardware for mounting the water blocks to either side of the Peltier devices. It included several strap pieces which are clamped by M4 machine screws.



The Interface shield sits on top of the stack as cables need to be plugged into its vertical headers. So the height of the components on this board is not critical. Note that the fuse holder is empty as 12V is supplied via V_{IN}. So we could have omitted S1, F1 and LK1.

Small springs ensure that a uniform and not excessive amount of clamping force is applied.

These straps are intended to clamp two water blocks, one each side of a row of Peltier devices. If you are using one water block and a heatsink, see below.

Start by assembling the water blocks and Peltier devices. This can be fiddly as several things need to come together at the same time and they will all have a coating of thermal compound.

Clean the water blocks and Peltier devices with isopropyl alcohol or similar to remove any contamination and residues. Allow it to dry.

Lay a row of straps on your workbench, with machine screws and washers fitted through the holes; the heads should face down. Rest one water block on top and apply a minimal amount of thermal compound to one side of each Peltier device, spreading it out.

The optimum amount of thermal compound is as thin as possible, but covering the entire area of the contacting surfaces.

Ensuring that the Peltier devices are oriented the same way, press them down onto the water block, sandwiching the thermal compound. If you have (for example) all the red leads to the left and all the black leads to the right, they should be oriented correctly.

Spread thermal compound onto the top of the Peltier devices, then rest the second water block on top of this, making sure that the barbed ends are oriented as you require.

Place the remaining strap pieces in place, followed by the springs, washers and then nuts. Tighten the nuts until the springs start to pull up.

Ensure that the Peltier devices are square and evenly spaced; at the very least, they should not protrude from the water blocks. The nuts can then be tightened down, ensuring that the springs are not compressed to the point that the coils are touching.

Using a heatsink instead

To test whether we could get away without a radiator, we used a heatsink much wider than the Peltier devices (40mm). Therefore, we could not use straps on both sides to pull the whole assembly together. If you have a heatsink that's 40mm wide, that may be possible, but you'd probably have to cut down a larger heatsink to get one the right size.

We recommend you use a larger heatsink anyway, as this will allow larger fans to be used, giving more effective heat transfer to the air.

Assuming your heatsink is significantly more than 40mm wide, you will need to drill and tap holes on the face of the heatsink to mount the Peltier devices.

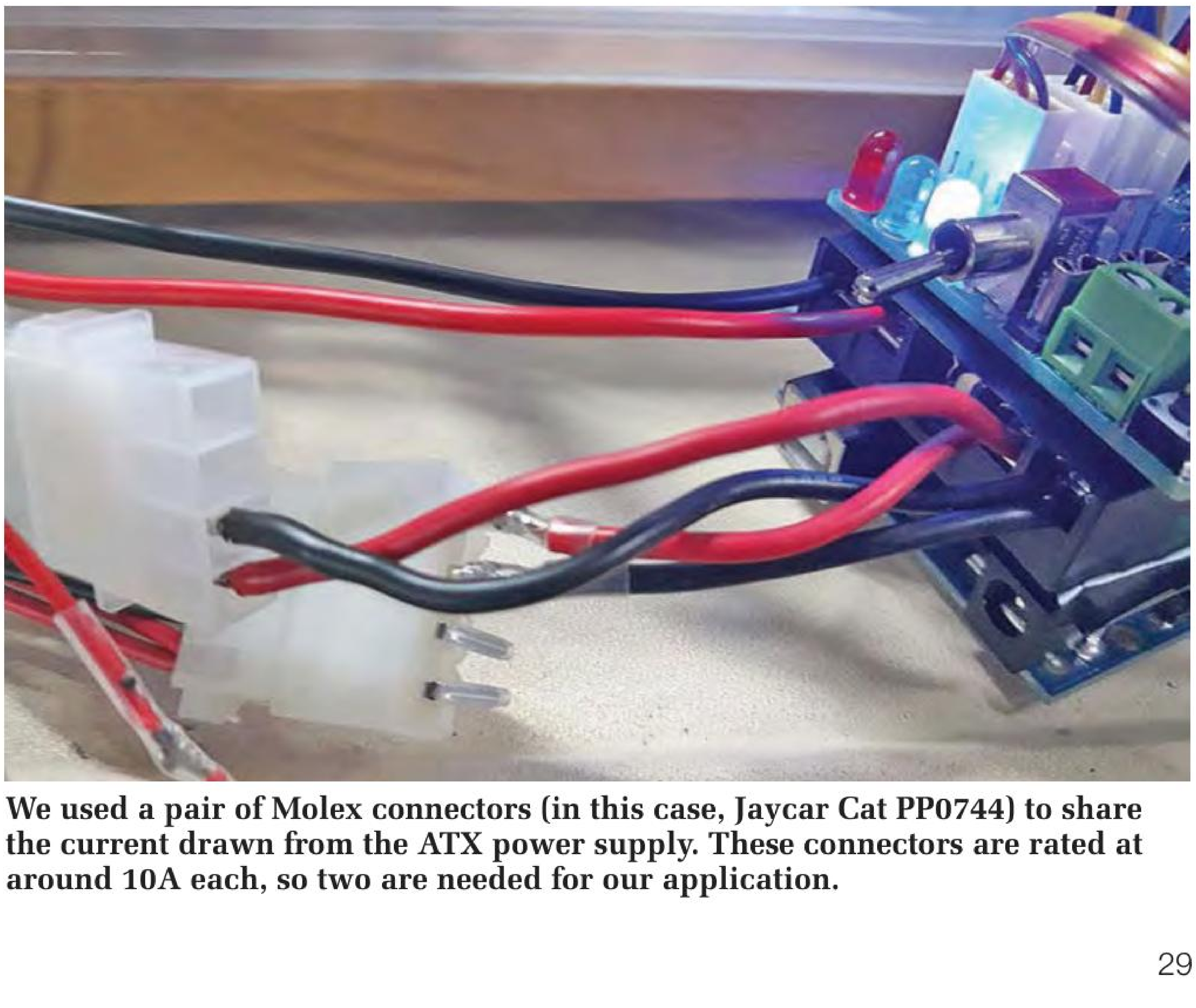
Lay out the Peltier devices and water block on the heatsink to determine where the holes need to be and mark them, lined up with the gaps between the fins if possible (this will allow the holes to be tapped through).

If you do not have a tap, and you can line the holes up with the spaces between the fins, instead of tapping you could drill right through and use long screws held in place by nuts fed in between the heatsink fins. We know from experience that this works but doing it is very fiddly.

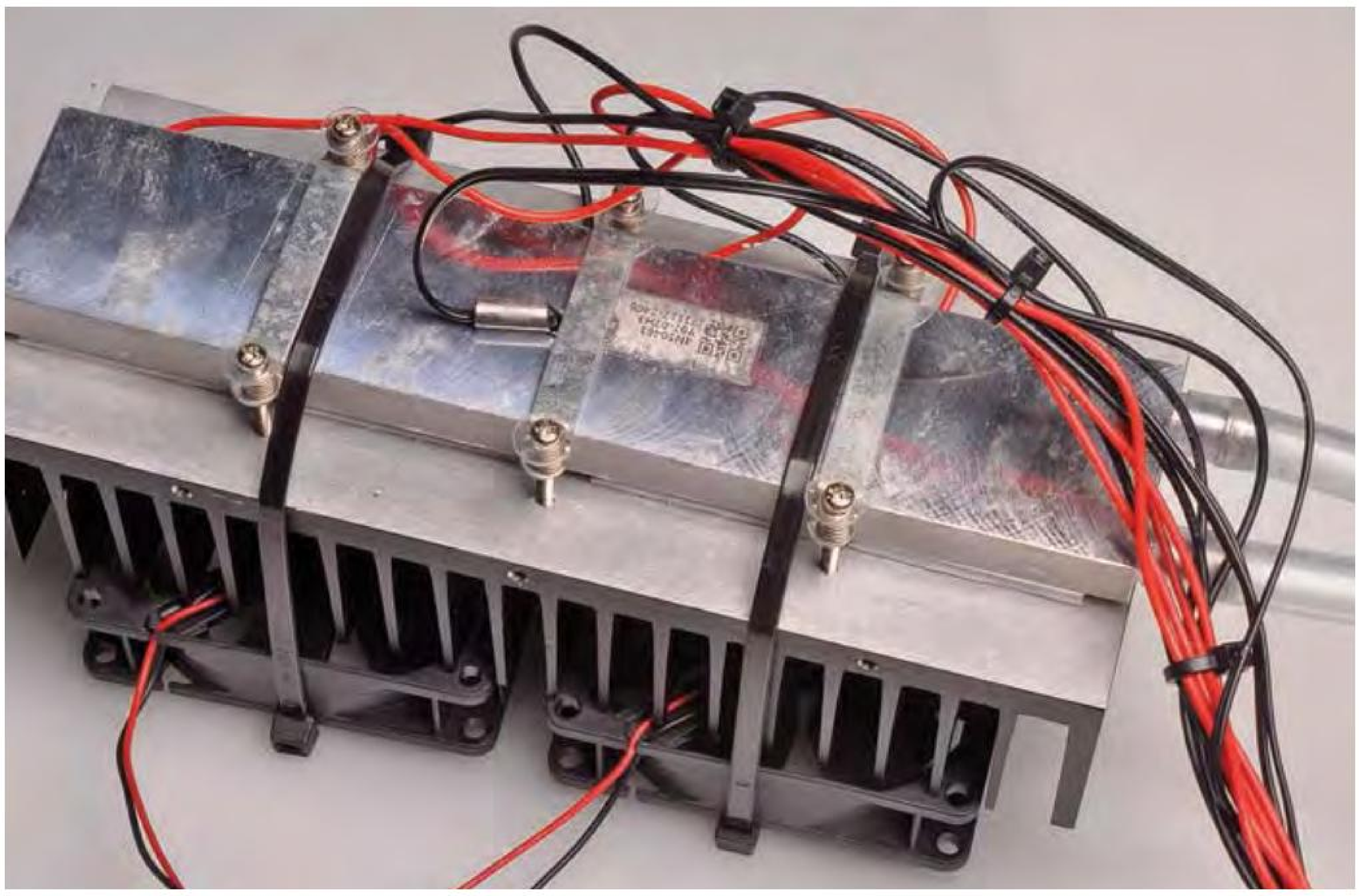
If you are tapping, drill holes to the diameter specified for that tap. The holes required are usually slightly smaller than the tap size. Many taps are supplied with appropriately sized drill bits.

Having drilled the holes, carefully tap them. Take your time with this and reverse the tap if it jams; this is usually enough to clear the swarf. You need to use a lubricant to help as well; we have used WD-40 or 3-in-1 oil with success, although kerosene is also said to be ideal for aluminium.

Clean any residue off the heatsink and sand down any high spots around the tapped holes. Since the brackets have a good amount of clearance from the Peltier devices, it is not critical that the site is perfectly flat.



We used a pair of Molex connectors (in this case, Jaycar Cat PP0744) to share the current drawn from the ATX power supply. These connectors are rated at around 10A each, so two are needed for our application.



The minimal hydraulic circuit (corresponding to Fig.5 from part one) uses a finned heatsink supplemented by fans to remove heat from the Peltier devices and water block. It's the same arrangement as used on many amplifier and power supply circuits.

Clean the water blocks and Peltier devices with isopropyl alcohol or similar to remove any residues and allow to dry.

Apply a very thin layer of thermal compound to both sides of each Peltier device and place it on the heatsink in the correct location. It's not a problem to adjust them, but it can be messy if the thermal compound gets everywhere.

Ensure that the Peltier devices are all facing the same way. As well as the coloured leads, many have identifying marks on one side only.

Rest the water block on top and then rest the straps on it. For each hole, first place the washer, then spring and thread the machine screw into the heatsink.

Once all have been started, check that everything is where it should be and then tighten the screws so that the springs pull up, but the coils are not touching.

For our tests, we mounted the fans with cable ties around the entire assembly. Your heatsink may be designed to have machine screws threaded directly between the fins, in which case this will work quite well.

Another option is to drill small holes through the fins near their tips. You can then thread cable ties through these holes and the fan mounting holes. In any case, ensure that the airflow from the fan is blowing towards the heatsink.

Pumps

The input (suction) side of the submersible pumps we've specified must be fully under the surface of the water, as they are not self-priming. Using the submersible type means that a hole does not have to be cut in the side of the water vessel, avoiding the possibility of leaks.

For our laser cutter application, we placed the pump near the top of the vessel; the intent here is that if there is a leak in the Peltier cooling circuit, only a small portion of the laser cooling water will be lost.

The pump could run dry, but that is better than having the laser fail.

We managed this by cutting a hole in the lid, which is a firm friction fit for the hose. If the hose is loose, a couple of cable ties can be used to limit vertical movement.

We found that if we placed the pump too close to the surface, a vortex would form, allowing air to be sucked in. The solution is to lower the intake, which will make a vortex less likely to form.

Since our pump was resting on the laser's pump in this vessel, we could not lower the pump, so we attached a small piece of hose and an elbow facing downwards to lower the suction point.

Another option is to simply increase the water level, if there is room to do so. You might find that after starting the pumps that the level drops due to water being moved to the piping and you may need to add water anyway.

As the water passes through devices such as the water block and radiator, it should enter at the bottom and leave from the top.

This is to ensure that any water bubbles can rise up and out. Any voids where air has collected internally will not be contributing to heat transfer, so these should be minimised.

The water path should return to the initial vessel to complete the circuit. We cut a second hole in the lid to fix the return pipe in place. It can also be locked in place with the judicious use of cable ties (or silicone sealant).

Position the return slightly above the water level. This will allow the return flow to be seen while minimising the amount of air entrained. Air is not a good conductor of heat and air in the water lines should be avoided.

If possible, position the return as far as possible (on the vessel) from the pump. This allows the water to mix freely and take on a uniform temperature.

With the water circuit complete, the pump can be tested by connecting it to a 12V supply. The return should be a steady, continuous stream, indicating that a good amount of flow is occurring.

Check for leaks and that there is no air trapped in the pipes. Top up the water if necessary. If there is no flow, check the pump polarity and flow direction. The pumps we used are quiet but audible.

With the pumps running, you could also try powering the fans and Peltier devices to see what kind of performance the system can achieve. Keep in mind that without any controls, the water can still get quite hot.

Once this is satisfactory, mount everything in place so that it does not move around. We found a spare shelf panel on which to mount everything.

Thermistors

The 10kΩ thermistors we are using came potted into a small ring lug for mounting. They also had a reasonable length of cable attached, so all we needed to do was terminate each thermistor with a polarised plug to suit the Interface shield.

The thermistors are not polarised, so it doesn't matter which wire goes to which pin.

But if you are looking to place a sensor in your brew liquid (as in our diagram), we don't suggest that you use these.

Instead, you would use one which is clad in food-grade stainless steel. These are available, but cost a bit more. You can mix and match thermistor types, as long as they all have the same nominal value and similar curves (check the specified beta value).

We weren't sure whether the beads we got were waterproof, so we shrank a good length of heatshrink tubing on those which were to be immersed in water, extending past the thermistor.

We then firmly clamped the free end in pliers, sealing it, although injecting silicone into the open end before clamping it would make a more reliable seal.

Another option is to assemble these from scratch, using leaded thermistors, wire and socket headers.

Our software has been written to work with either 10kΩ or 100kΩ thermistors; just be sure to check the code before compiling to make sure that it's expecting the values that you've used.

We prefer 10kΩ types as these are less likely to be affected by EMI or other stray fields.

Mounting the thermistors

The small ring lug on the thermistors we used made mounting them straightforward. Although we did not end up using the heatsink option, a simple tapped hole and machine screw would be adequate to fasten the thermistors to the heatsink.

For the radiators, an existing mounting screw was co-opted to thread through the thermistor's mounting hole and thus fasten it.

As noted above, the thermistor used in the circulating water must be thoroughly waterproofed. It should also be mounted to prevent it from falling in above the sealed part, if it is not fully sealed.

If it does not need to be removed, a pair of small holes in the side of the container (above the waterline!) could be used to thread a cable tie around the thermistor lead.

Attaching the thermistors to the water blocks (and thus near the Peltier devices) was quite straightforward. We simply loosened one of the mounting straps and slipped the flat end of the thermistor under the strap before tightening.

Power supply

To power our *Thermal Regulator*, we used a spare ATX power supply, as designed for use in a personal computer.

This is an attractive option if you have a surplus unit available. But if you have to purchase one, they are also relatively inexpensive, and can be quite efficient.

An alternative is one of the many open-frame power supplies that exist. Altronics M8692 is such a device. You will need to do some mains wiring to use this unit; the mains wires are exposed but protected behind a barrier strip.

It is intended that this sort of supply is installed inside an enclosure and we think this is wise, whatever your power supply, as it will help to keep the water and electronics separate. If the enclosure is metal, be sure to earth it properly.

The 12V wiring needed for this sort of supply is straightforward and requires nothing more than a 30A twin cable (ideally red/black) to be terminated at each end.

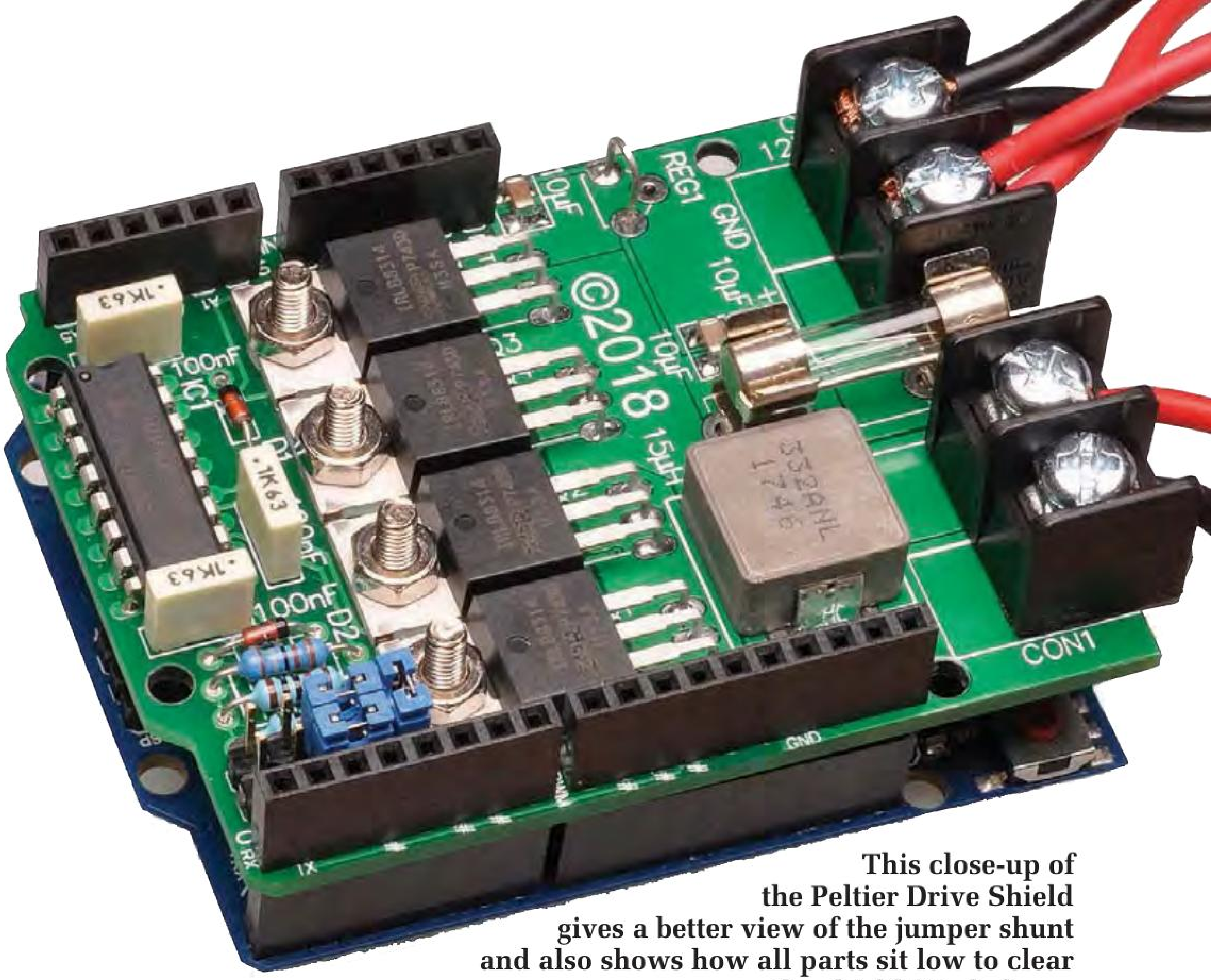
ATX power supplies need a bit more work on the 12V side but only require an IEC type lead to be plugged in to supply the mains.

There are usually multiple 12V (yellow) and GND (black) wires; you will need to use several of each to ensure that you can draw sufficient current.

ATX power supplies also have a power signal that needs to be pulled low to command the power supply to start. This wire is usually coloured green; we simply used a jumper to short it to an adjacent ground wire. See the photos which show how we wired up our supply.

If you are sure you do not need the power supply for use on a computer in the future, then several yellow wires (12V positive) and black wires (ground) can be bundled together and spliced into a single pair of high-current conductors.

Whatever your source of power, connect it to the 12V input terminals on the Peltier Driver shield. The positive terminal is the one closest to the fuse.



This close-up of the Peltier Drive Shield gives a better view of the jumper shunt and also shows how all parts sit low to clear the shield fitted above.

Wiring it up

You may need to take the Arduino stack apart to wire the Peltier devices to the Peltier Driver shield. The orientation with which the Peltier devices are connected will determine the voltage polarity required for heating or cooling, but it is easy to change the software if it is reversed, so don't worry about it too much. Just make sure they are all connected with the same polarity.

We used a small piece of terminal strip to break out the connections; it also allows us to run the short leads on the Peltier devices further from the Driver shield.

Fit the Uno below and the Peltier Interface shield above. Plug in the fans, I^{2}C LCD and thermistors. See Table 1 for which thermistor should be plugged into which header. If necessary, the sensor mapping can also be changed in software.

The pump(s) connect to the two screw terminals near IC2. Check that the polarity is correct as the pumps will not work correctly if they are spinning backwards.

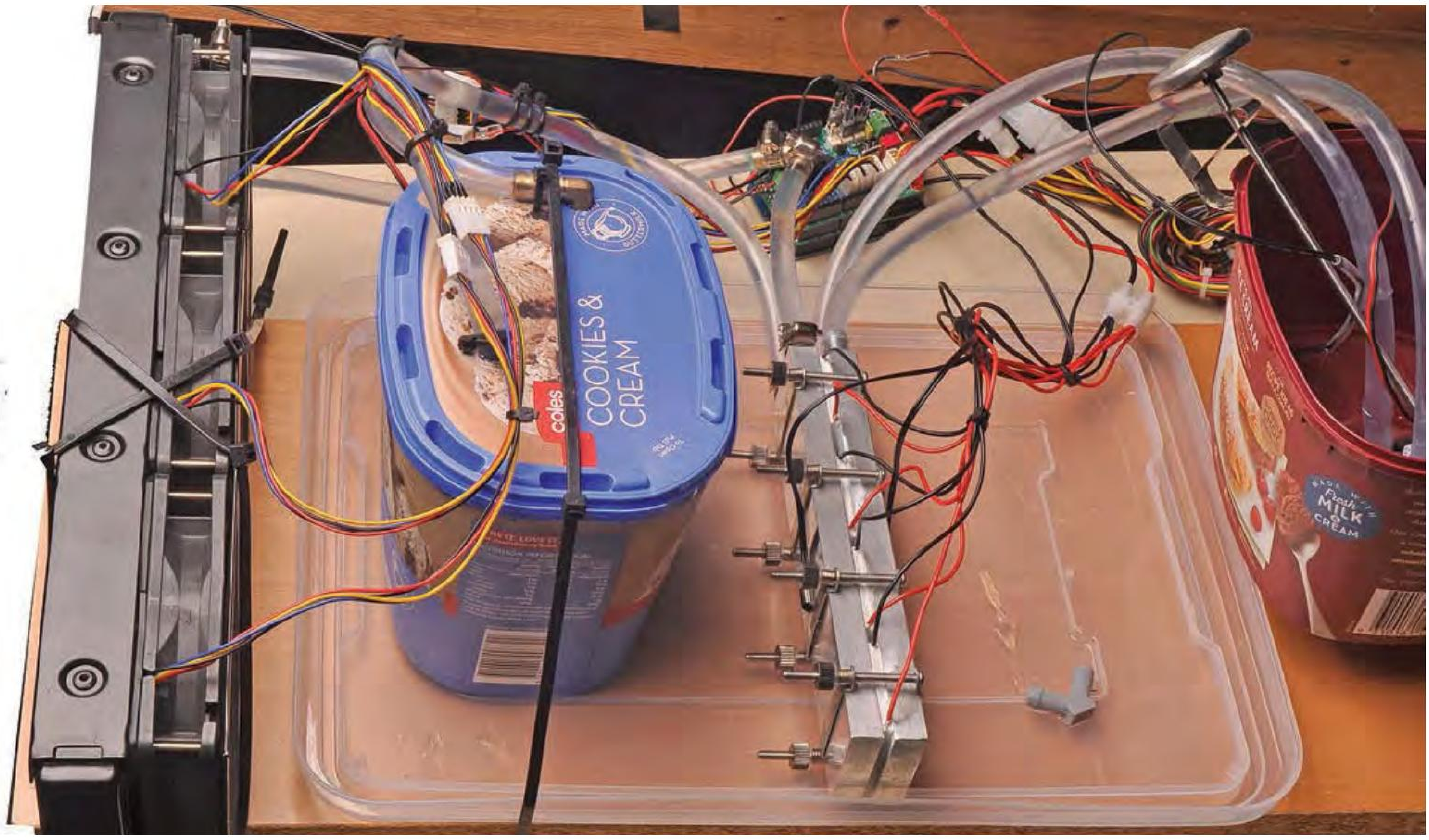
If you have a separate 12V supply for the Peltier Interface shield, connect that now. Only a fairly small fuse is needed (say, 3A) unless you have some very large fans and pumps.

Control software

The software we have written is somewhat basic but provides most or all of the necessary functions for a variety of jobs. It measures the temperature of all six sensors, but only uses the data from three to make decisions. The remaining temperatures are displayed but not used by the control software.

You will need to install the Arduino Integrated Development Environment (IDE) to program the Uno board, and this also contains everything you need to customise the software, if you choose to do so.

We used IDE version 1.8.5, and suggest that you do the same to avoid any problems which may occur due to changes between versions.



This view shows our complete system which will be installed in our laser cutter. The plastic tray was in case of leaks.

As with many advanced Arduino projects, some external libraries are needed. They might seem complicated, but using them is easier than having to write our own interface functions. These are all included in the download package, along with the Arduino 'sketch' (program code) itself. The package is available for download from the April 2021 page of the *PE* website.

The I2CLCD library is one we have adapted from another open-source library. We have added the ability to auto-detect the I^{2}C address of the LCD.

The easiest way to add this library is to copy the 'I2CLCD' folder from the .ZIP archive to your libraries folder (in Windows, this is inside your Documents folder, within a subdirectory called 'Arduino').

You might as well copy the remaining three supplied libraries too, as the versions we have included are known to work.

These three libraries can also be installed by finding them by name in the Library Manager. To do this, search for 'OneWire', 'DallasTemperature' and 'Irremote' and install each in turn. If you already have folders with one of these names, you may already have the library installed, so you probably don't want to overwrite it unless you find our sketch doesn't work.

If you install libraries by copying the files, you may need to close and re-open the Arduino IDE for it to detect them.

Preparing the sketch

We won't go into too much detail of the sketch operation here, as you can easily examine the source code.

It works by scanning the thermistors once per second, along with the fan's tachometer signals. At the same time, any received infrared commands are processed. It selects a mode (heating, cooling or off) depending on the above, and then updates the fan, pump and Peltier control signals.

The sketch is well-documented with inline comments, so these are a good place to start if you want to dissect and change the code.

We named the project sketch **Peltier_Controller_V10**, although this may change if we update it.

For the programming stage, you might like to remove the Uno from the board stack and connect it (by itself) to the computer's USB port. This will avoid any problems that might occur with the fact that the IR receiver signal is shared with one of the pins thst is used for programming.

If your Peltier 'rig' is not near your computer, this can also make your life easier.

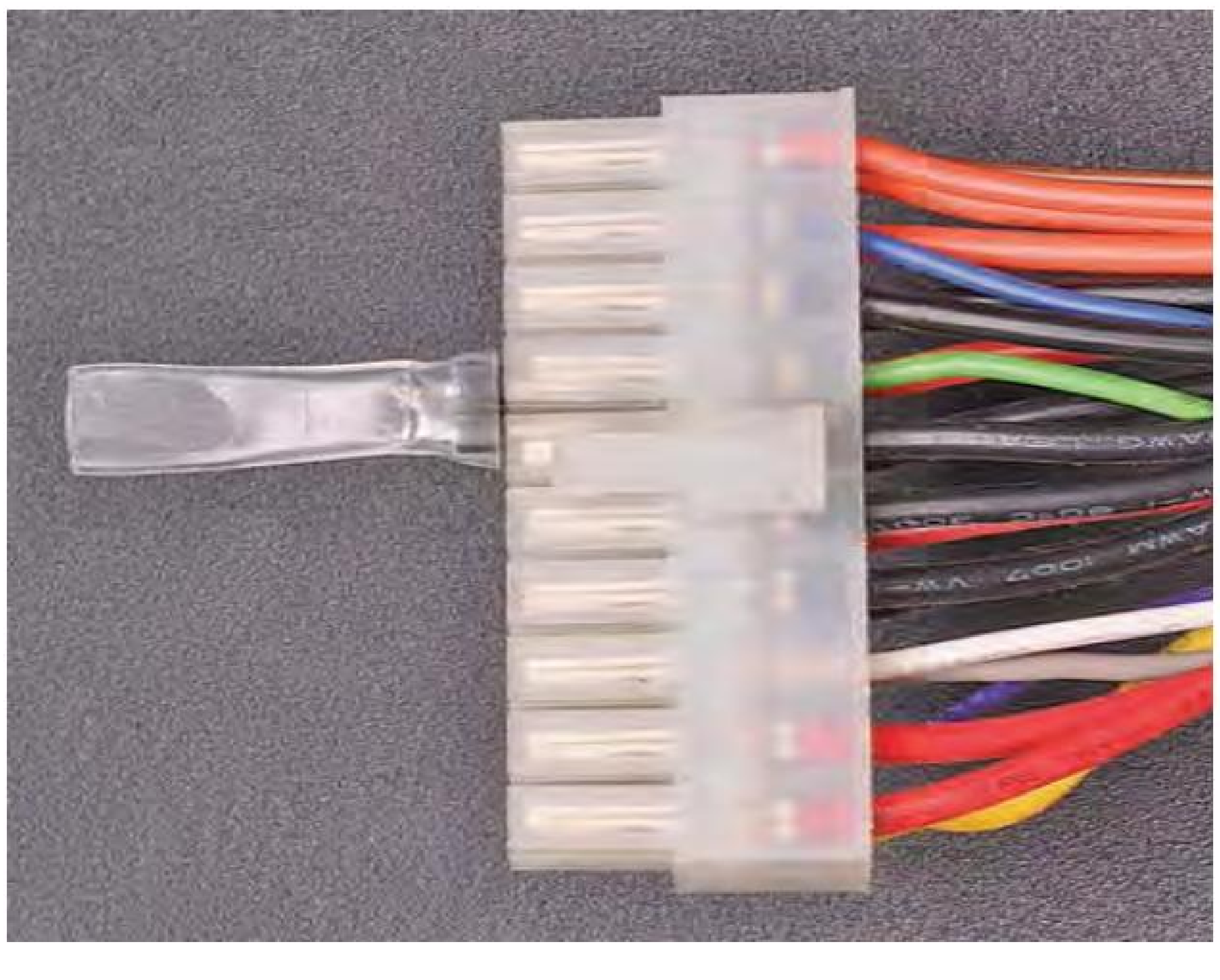
Open the sketch file, select Uno from the Tools→Board menu and ensure that the correct serial port is selected. Upload the sketch (CTRL+U), and assuming that's successful, detach the USB cable and replace the Uno in the board stack.

The display should spring to life, showing an array of temperatures. Nothing else should happen yet.

By default, the sketch accepts commands from a Jaycar XC3718 remote control, or an Altronics A1012 universal remote set to use TV code 089. Other remote controls programmed with a Philips TV protocol may also work fine.

Basic operation

There are four basic modes: full heating, full cooling, proportional control with a fixed target temperature, or



ATX power supplies require the green wire to be pulled to 0V (any black wire) to turn on. We made a simple jumper with a 2-pin header and some heatshrink; the power supply now activates when it receives 230V.

proportional control following a temperature profile that's defined in the sketch.

For the first two modes, the Peltiers are driven at full pelt (hah!) with one polarity or the other. In each mode, the LCD shows a variety of status information, as seen in the accompanying photos.

In the last two modes, the unit tries to maintain the main thermistor temperature (T1) at the desired value by heating or cooling to varying degrees, as needed.

The following buttons on the remote control can be used to control it:

- CH+ and CH- (on either type of remote) enable full heating and full cooling respectively. A second press of either of the same button turns the *Thermal Regulator* off.
- To program a setpoint for the third (fixed temperature) mode, enter three digits on the numeric keypad; the entered number is divided by ten to give the target temperature. For example, entering 1, 2, 3 will set the target to 12.3°C. This can only be done while the unit is idle, as it might otherwise cause it to change between heating and cooling rapidly.
- Pressing the power button (on the Altronics remote) or play (on the Jaycar remote) will start or stop operation in setpoint mode. The setpoint can be tweaked in this mode by using the volume up and down buttons. This can be done while it's operating as small changes are OK in this case.
- The temperature profile mode is activated by pressing the EQ button on the Jaycar remote or '-/--' on the Altronics remote.

Instead of showing the fan speeds, the LCD indicates the time, step number and next timed target. The unit steps through the array of temperature/time points set in the sketch, interpolating the temperature between each point.

This could be used to implement the timer-based sous-vide cooker that we mentioned earlier, or a brewing or cheesemaking profile determined by the exact product you are trying to make. You can usually get an idea of the profile you will need from a recipe, but some experimentation and tweaking may be required to obtain the best result.

Troubleshooting

You can check whether your Peltier devices are wired with the expected polarity by putting the unit in full cooling mode and then checking that the main sensor temperature (T1) goes down rather than up. If it goes up, then comment out this line in the code by adding '//' to the beginning:

```
setBipolar((pDrive*PWM_TOP)/100); //scaled output
```

ie,

```
// setBipolar((pDrive*PWM_TOP)/100); //scaled output
```

and remove the '//' from the start of this one:

```
// setBipolar(-(pDrive*PWM_TOP)/100); //scaled output,
```

ie,

```
setBipolar(-(pDrive*PWM_TOP)/100); //scaled output,
```

If the LCD doesn't light up or displays nothing, check the red LED is flashing rapidly. If so, the software did not detect the I^2C module, so it could not initialise and control the display.

Our sketch includes code to automatically detect the I^2C address of the display, so it should work if the LCD is connected correctly. Check your wiring and reset the Arduino by pressing the RST button on the Peltier Interface shield. If this does not fix the problem, there may be a problem with your LCD module.

Sensor	Location
TS1	Temperature to be regulated
TS2	On Peltier water block, TS1 loop
TS3	On Peltier water block, opposite loop from TS1 and TS2
TS4	On radiator/heatsink, same loop as TS3
TS5	Spare (currently unused)

Table 1 – thermistor connections

The connections we made on our prototype are shown here; although only the first three are critical for the software to be able to control the Peltier devices.

Now what?

We've presented a good number of options and uses this circuit can be put to, but we don't have the space to go into detail on all the possibilities.

There are many ways that you could modify the code to suit your application. For example, you could add a DS3231-based real-time clock module to your Arduino by connecting it to the I^2C pins. That would allow you to set up the code to automatically start and stop the unit at preset times.

Or, you might want to modify the code so that you can have multiple temperature profiles set up to suit different processes, with a way to select between them (eg, pressing different buttons on the remote control).

There are so many ways that this project can be used; we would love to hear from our readers about the applications they come up with for the *Thermal Regulator!*

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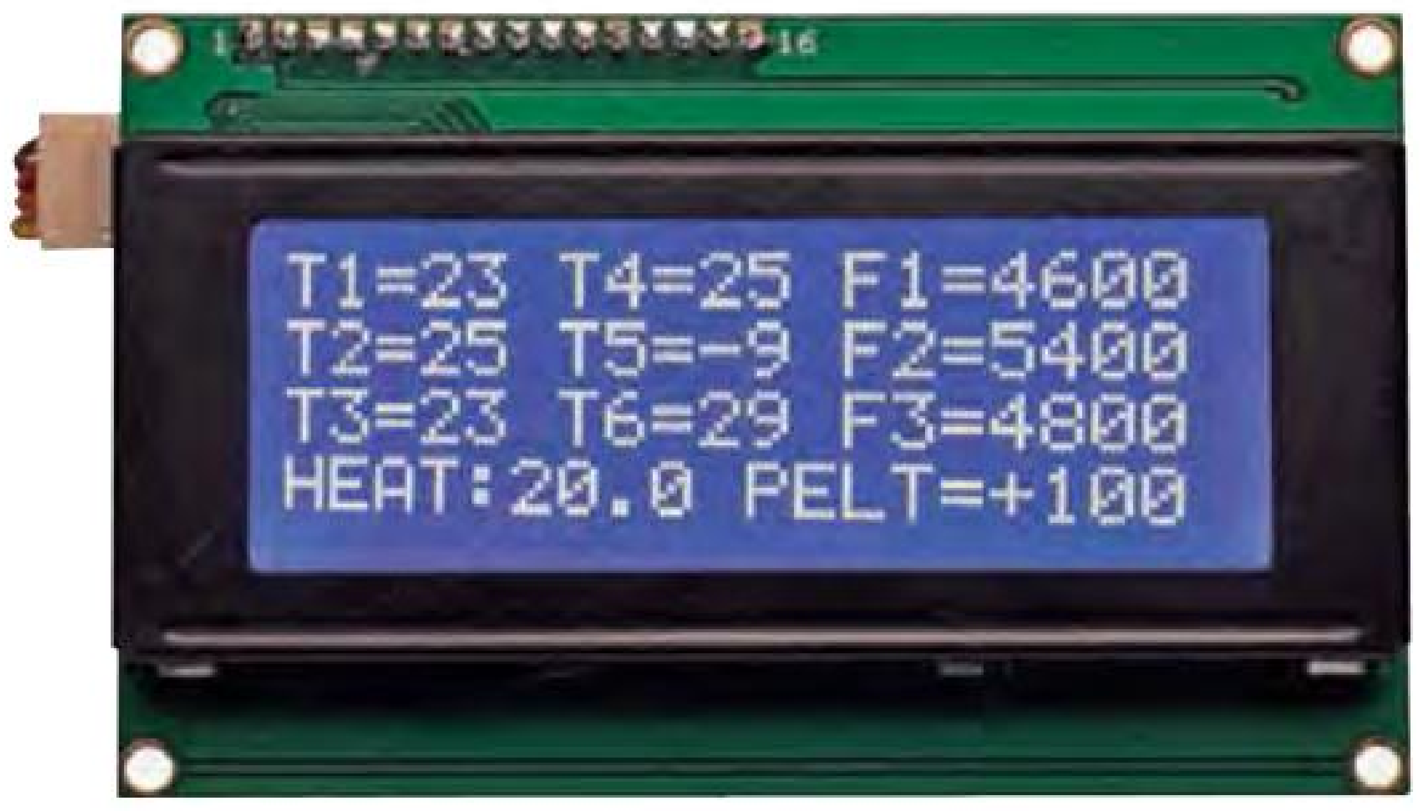
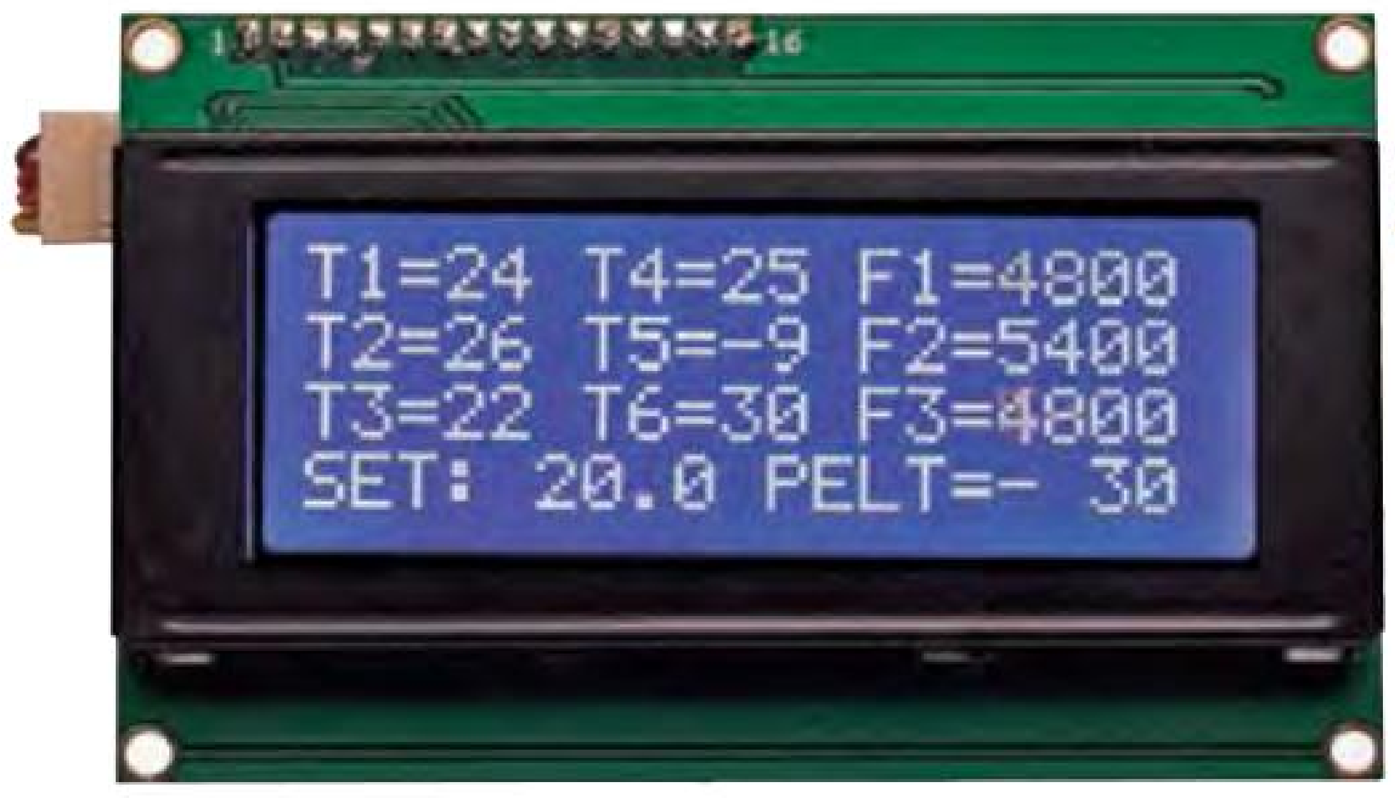


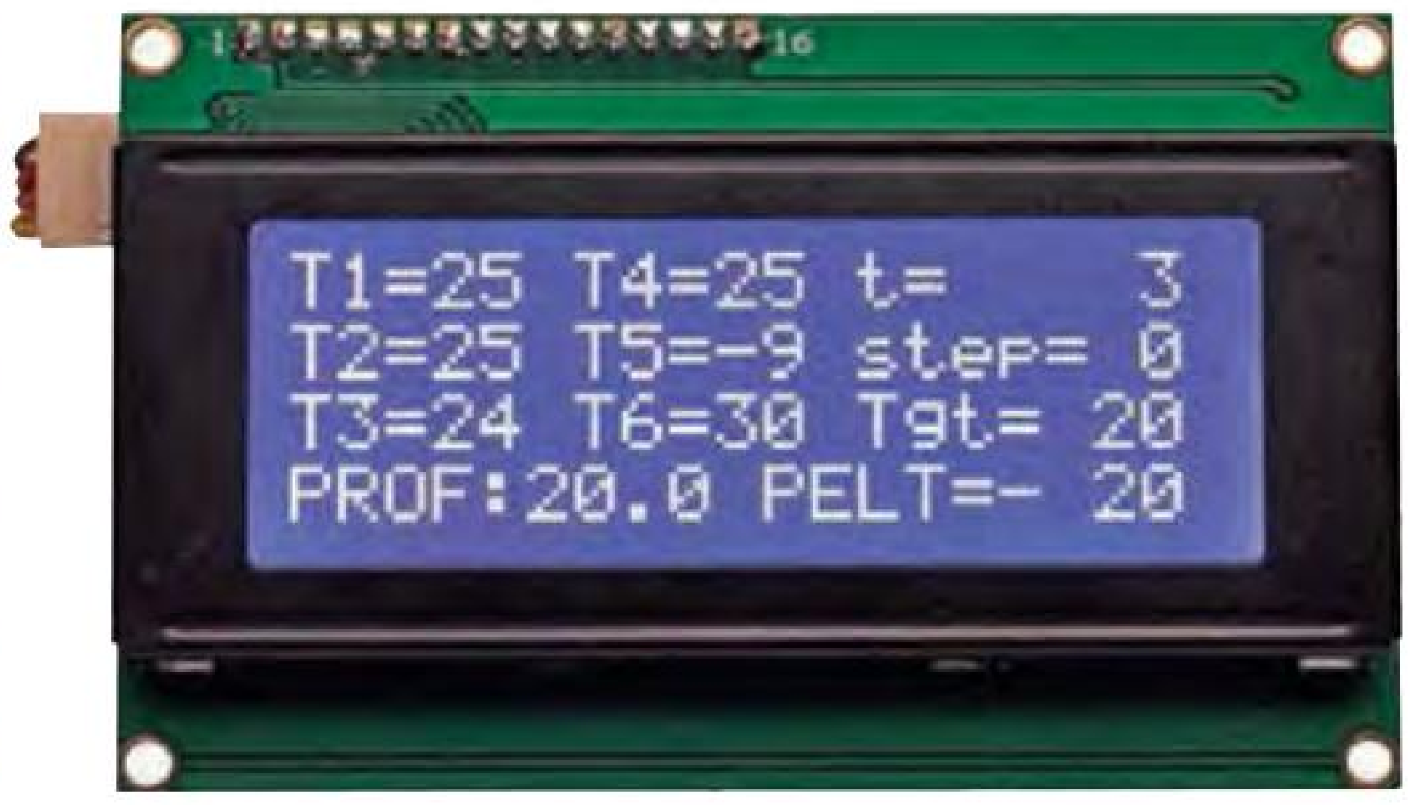
```
T1=23 T4=25 F1=4600
T2=25 T5=-9 F2=5400
T3=23 T6=29 F3=4800
HEAT:20.0 PELT=+100
```

In most of the modes, the temperature and fans speeds are displayed. This shows Heating mode, which drives the Peltier devices at +100%; Cooling mode uses –100%



```
T1=24 T4=25 F1=4800
T2=26 T5=-9 F2=5400
T3=22 T6=30 F3=4800
SET: 20.0 PELT=- 30
```

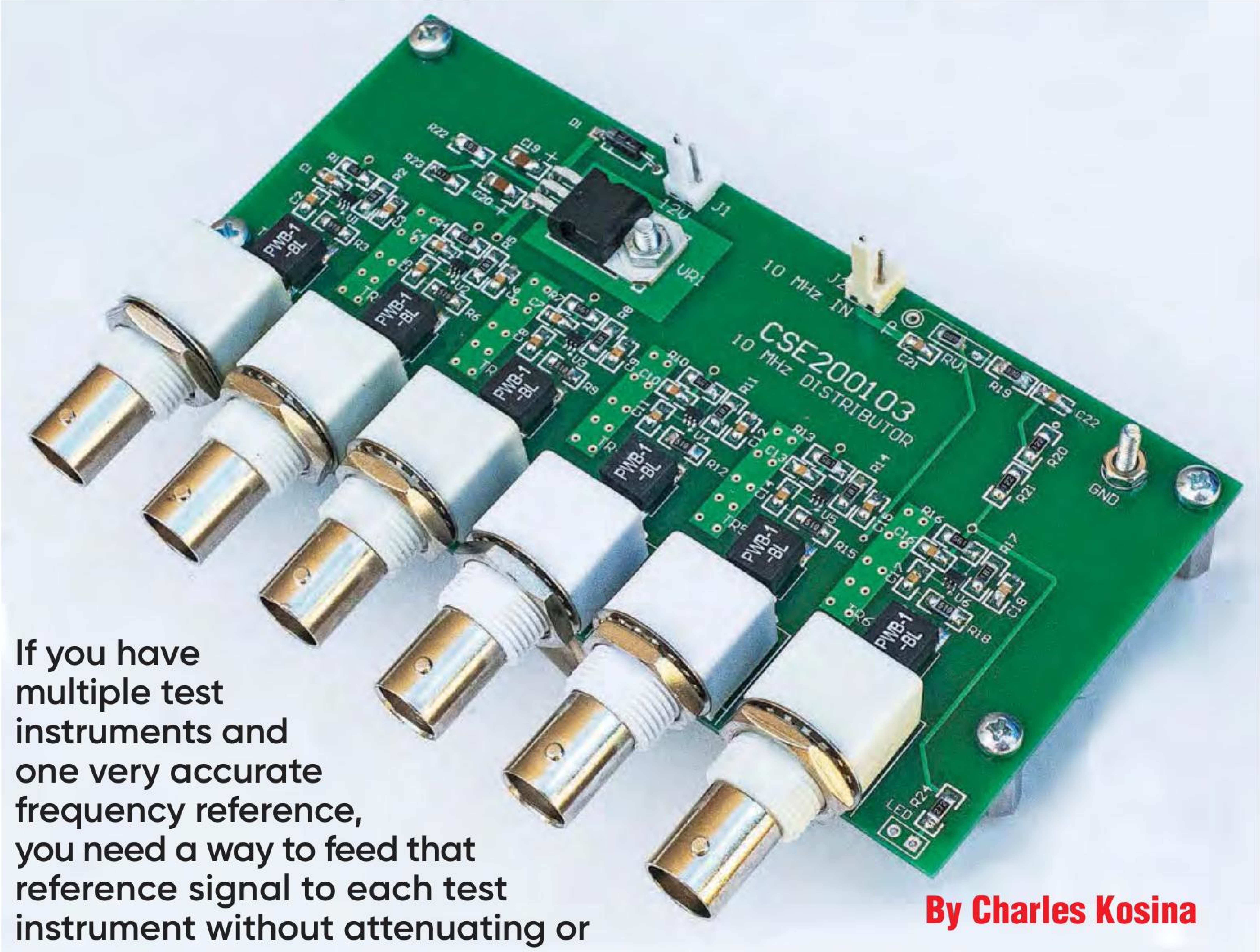
In Set mode, the Peltier Controller modulates the PWM to drive the T1 temperature (top left) towards the setpoint (bottom left). In this case, moderate cooling of 30% is needed.



```
T1=25 T4=25 t=    3
T2=25 T5=-9 step= 0
T3=24 T6=30 Tgt= 20
PROF:20.0 PELT=- 20
```

In Profile mode, the setpoint is varied according to a timed series of temperature points with ramps in between. Instead of fan speed, the time, step number and ramp target are shown at right.

Frequency Reference Signal Distributor



If you have multiple test instruments and one very accurate frequency reference, you need a way to feed that reference signal to each test instrument without attenuating or degrading the signal. That's precisely what this device does. It has one input and six outputs, and while it's designed with a 10MHz reference in mind, it can handle other frequencies too.

By Charles Kosina

This design was prompted by a ham radio friend who has a GPS-disciplined 10MHz frequency reference and needs to feed its output to several different pieces of equipment.

This means that not only are they operating with maximum accuracy (those with internal references aren't always spot-on), but they are also in lockstep.

A typical 10MHz reference signal generator has only a single output, and this cannot easily be fed to more than one device. You can't just use a Y-cable since it will then have a 25Ω (or lower) load rather than a 50Ω load, which would certainly reduce the signal level and might also overload the generator and potentially cause other problems.

You really want a +10dBm (0.7V RMS) reference signal terminated with 50Ω at the reference input of each instrument. I decided on a design that will provide six such outputs. In principle, it is elementary. It comprises just six high-bandwidth op-amps feeding the outputs through broadband HF transformers, giving six fully isolated and buffered outputs.

Circuit design

Fig.1 shows the circuit design. The incoming reference signal is fed via BNC connector CON1 and pin header CON2 onto the board. It is then AC-coupled to VR1, a 100Ω trimpot which is used to adjust the output level. The bottom end of the pot connects to a +3.5V half supply DC bias source via a 39Ω resistor. The bottom of the resistor is bypassed to ground, so the input impedance is 139Ω (100Ω+39Ω).

This is a little higher than the 50Ω or 75Ω that most generators are designed to drive, but the VSWR on the short run of coax from the generator will not be significant, so this should not cause any problems. If anything, this means that the *Distributor* gets a signal with a slightly higher amplitude, so less gain is required to achieve +10dBm.

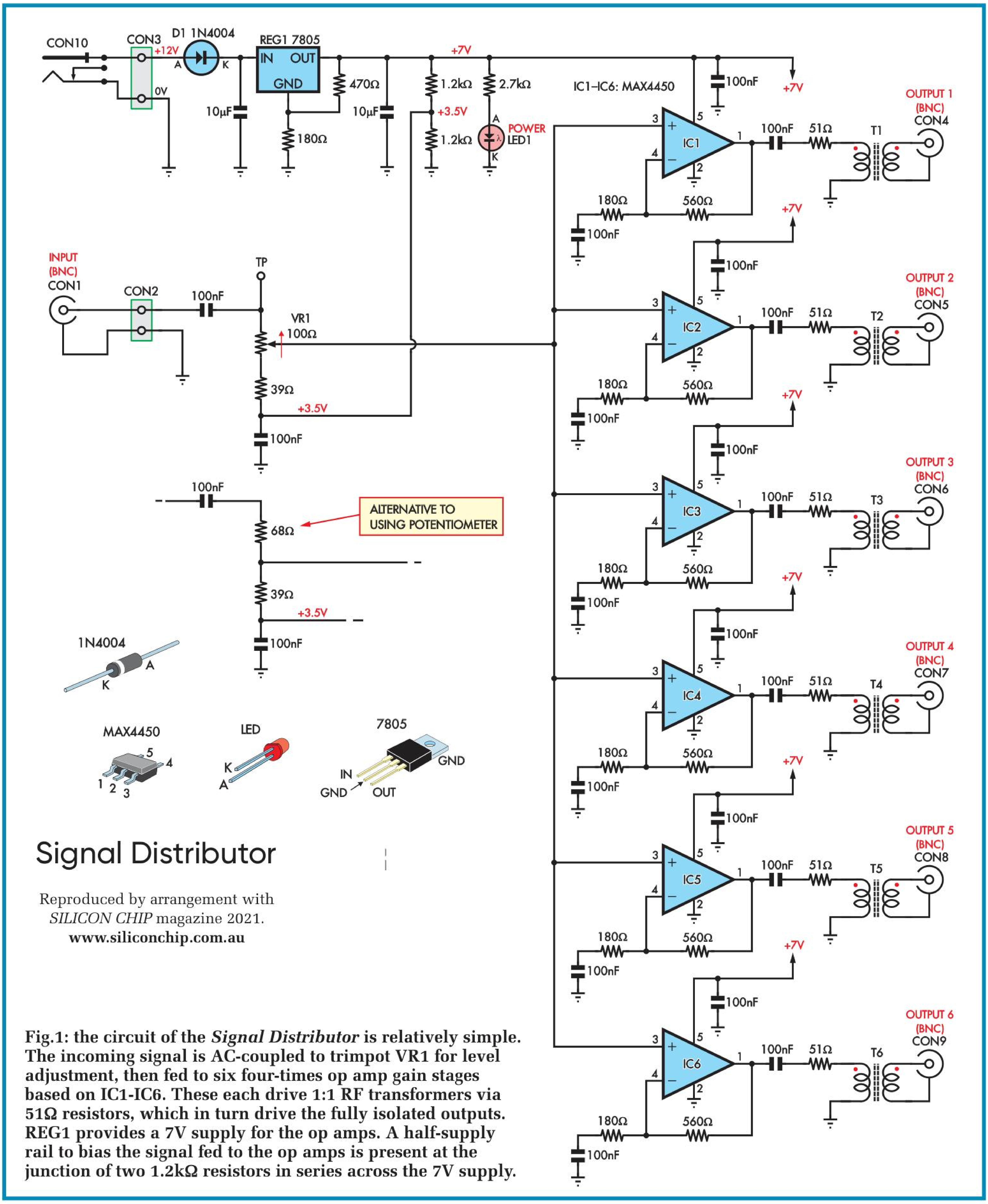
The +3.5V half supply rail is simply derived from the regulated 7V supply rail via a 1.2kΩ/1.2kΩ resistive divider. The 100nF bypass capacitor to ground attenuates any supply noise which makes its way through the regulator and this divider, so it doesn't affect the signal.

The signal is then fed to the six op amp non-inverting inputs (pins 3 of IC1-IC6), which are all connected in parallel.

For the op amps, I decided to use MAX4450s which each have a gain bandwidth of 210MHz. So for a 10MHz signal, the open-loop gain is about 21. They are configured as non-inverting amplifiers and the 560Ω/180Ω feedback resistors give a gain of about four.

The bottom end of each feedback divider connects to ground via a 100nF capacitor. The feedback network cannot be connected directly to ground due to the +3.5V DC signal bias, and also cannot connect to the +3.5V reference since it is unbuffered and thus has a high source impedance (600Ω).

Each op amp has a 100nF supply bypass capacitor for stability. Their outputs are capacitively coupled to six Coilcraft 1:1 broadband transformers, T1-T6. A 51Ω series resistor sets the source impedance for the transformer drive close to the required 50Ω.


CON10
CON3
+12V
0V
D1 1N4004
A
K
REG1 7805
IN
OUT
GND
10µF
470Ω
180Ω
+7V
1.2kΩ
2.7kΩ
+3.5V
1.2kΩ
A
POWER
LED1
K
IC1–IC6: MAX4450
100nF
+7V
OUTPUT 1
(BNC)
CON4
3
5
4
1
2
IC1
51Ω
T1
560Ω
INPUT
(BNC)
CON1
CON2
TP
VR1
100Ω
39Ω
+3.5V
IC2
OUTPUT 2
(BNC)
CON5
T2
IC3
OUTPUT 3
(BNC)
CON6
T3
ALTERNATIVE TO
USING POTENTIOMETER
68Ω
IC4
OUTPUT 4
(BNC)
CON7
T4
IC5
OUTPUT 5
(BNC)
CON8
T5
IC6
OUTPUT 6
(BNC)
CON9
T6
1N4004
MAX4450
LED
7805

Signal Distributor

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Fig.1: the circuit of the *Signal Distributor* is relatively simple. The incoming signal is AC-coupled to trimpot VR1 for level adjustment, then fed to six four-times op amp gain stages based on IC1-IC6. These each drive 1:1 RF transformers via 51Ω resistors, which in turn drive the fully isolated outputs. REG1 provides a 7V supply for the op amps. A half-supply rail to bias the signal fed to the op amps is present at the junction of two 1.2kΩ resistors in series across the 7V supply.

The six BNC output connectors are isolated from ground; they are grounded by the instrument being fed, eliminating the possibility of any Earth loops. The transformers have a 50Ω output impedance, suiting virtually all device reference inputs.

IC1-IC6 have a supply voltage range of 4.5-11V; I am using 7V as this gives enough headroom for the required output voltage swing.

This is supplied by REG1, a 5V fixed regulator which has its output voltage raised to 7V by a 470Ω/180Ω voltage divider between its output and GND pins and circuit ground. The 7V rail also supplies around 2mA to power indicator LED1 via a 2.7kΩ current-limiting resistor.

REG1's output is filtered by a 10µF capacitor, and its input is similarly bypassed. It is supplied with around 12V DC via header CON3 and reverse polarity protection diode D1. CON3 can be wired to a chassis-mounted DC barrel socket.

Note that the circuit shows that you can replace trimpot VR1 with a 68Ω SMD resistor if you don't need to be able to set the gain exactly. We won't go into any more details about this option (and that part is not in the parts list), so if you want to build it that way, check out our board photos as that is how the prototype was built.

PCB design

A good ground plane is essential for stability. Most components are surface-mount types, allowing most of the underside of the board to be a solid ground plane. The resistors and capacitors are metric sizes: 2012 (2.0 × 1.2mm/imperial 0805) and 3216 (3.2 × 1.6mm/imperial 1206), which are quite easy to solder.

The MAX4450 op amps are tiny chips as they only come in SOT-23-5 packages, so they require special care in assembly, but those with SMD assembly experience should be able to manage them with no real difficulties.

Performance

The signal from the GPS-disciplined oscillator is a clean sinewave of 2.9V peak-to-peak (about 1V RMS or +13dBm). Its second harmonic is at –40dB, the third harmonic at –50dB and it has no significant higher harmonics. The outputs from the *Distributor* into 50Ω loads are similar, with the harmonics down by more than 40dB.

Fig.2 shows the shape of the output waveform on my scope, while Fig.3 is a spectrum analysis of this waveform. The vertical scale is 10dB/div, which makes the second harmonic –44dB, the third harmonic –46.5dB and the fourth –46dB.

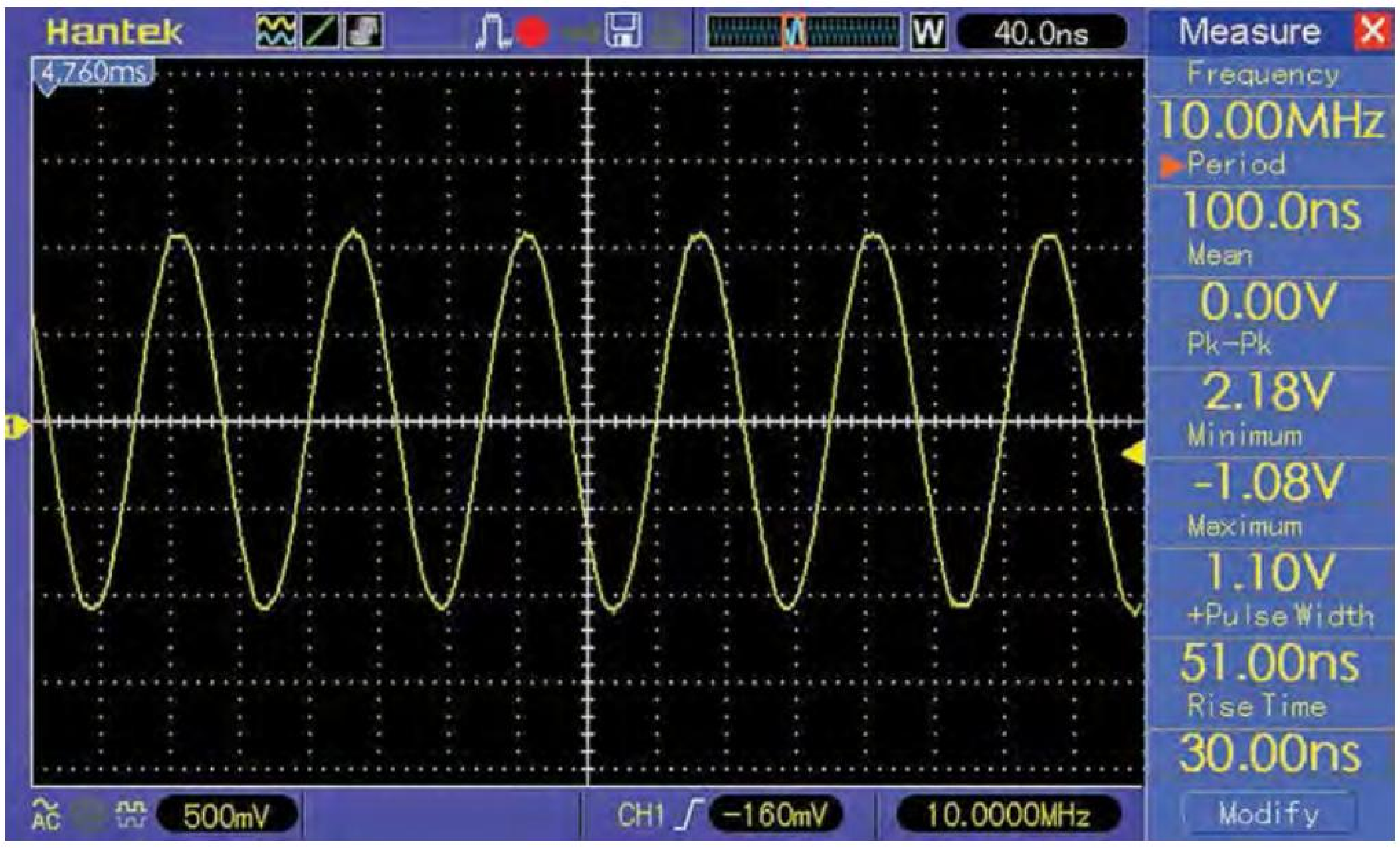


Fig.2: the scope grab of the signal from one of the unit's outputs shows an amplitude of 2.18V peak-to-peak, which is just over +10dBm. And as you can see, the frequency is reading exactly 10.00MHz.

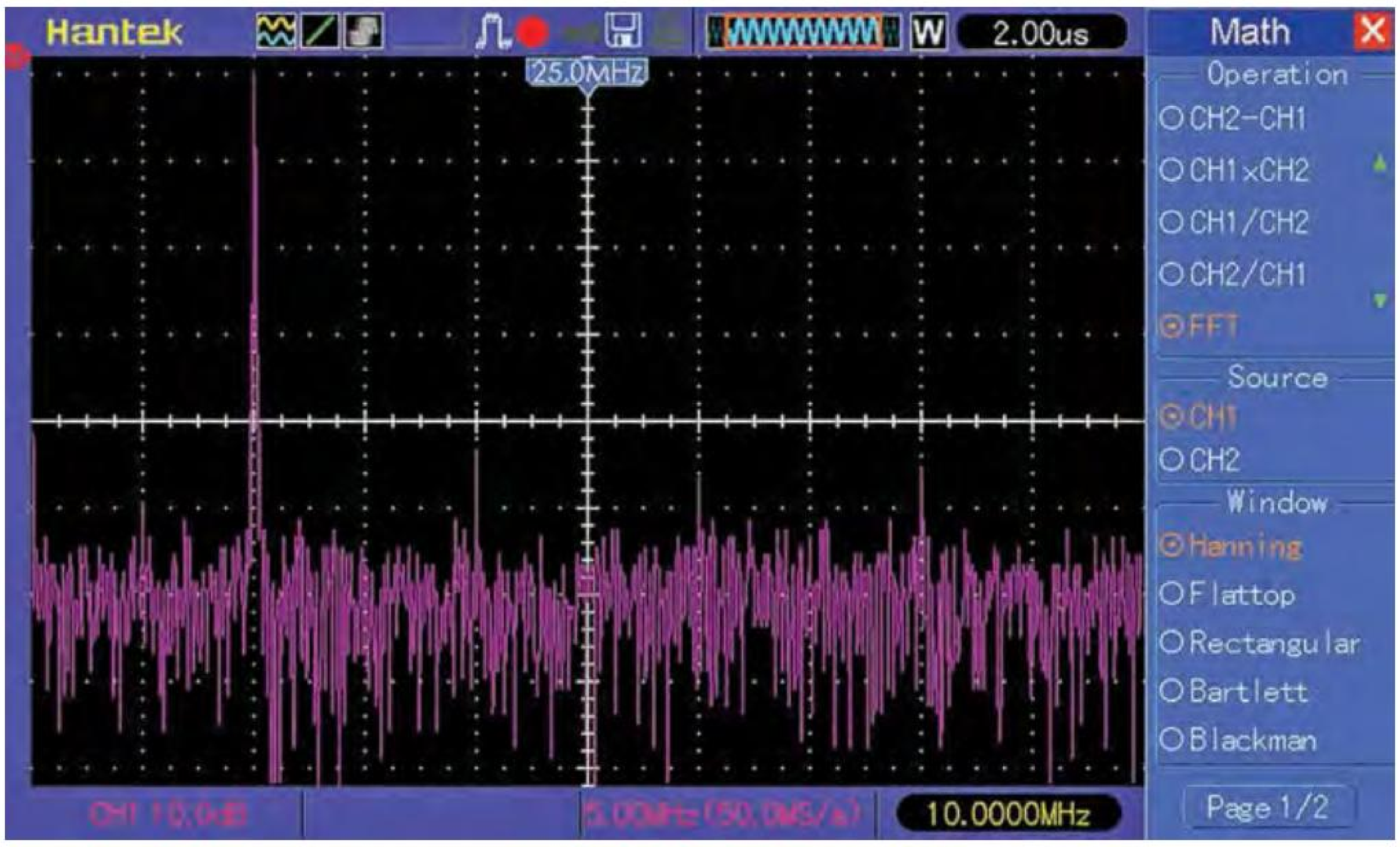


Fig.3: the scope was also used to produce this spectrum analysis of the output waveforms, which demonstrates that harmonic distortion is low, with the first three harmonics all well below –40dB.

Construction

The *Signal Distributor* is built on a PCB coded CSE200103 which measures 125.5 x 60mm. Refer to Fig.4, the PCB overlay diagram, which indicates which parts go where.

Start with IC1-IC6. These are the only ones with small pins close together. As they have two pins on one side and three on the other, their orientations should be obvious.

Tack them down by one of the two pins which are more widely spaced, then check the part is sitting flat on the board and that all the pins are over their pads before soldering the other four. If necessary, re-melt the first joint and nudge the part.

Once all the pins have been soldered, check that there are no bridges. If there are, apply some flux paste and use solder wick to soak up the excess solder. That should leave just enough solder to form good joints which are not bridged.

Next, solder all the SMD resistors and capacitors, referring to Fig.4 to see which goes where.

Their orientation is not important; simply tack down one side, check the part is flat on the PCB and not too crooked, then once you are sure the first joint has solidified, solder the other side. Ensure in each case that the solder adheres to both the part and the PCB pad.

The last set of surface-mounting parts are transformers T1-T6. These are not entirely symmetrical, as they have a centre-tap on one side only, but we don't connect to that tap. So it doesn't matter which way you fit them, although we suggest you match the orientation shown in our photos to guarantee you get the stated performance.

Use the same technique as with the smaller SMDs, tacking one pin and then checking the remaining pin locations are square over their pads before soldering them.

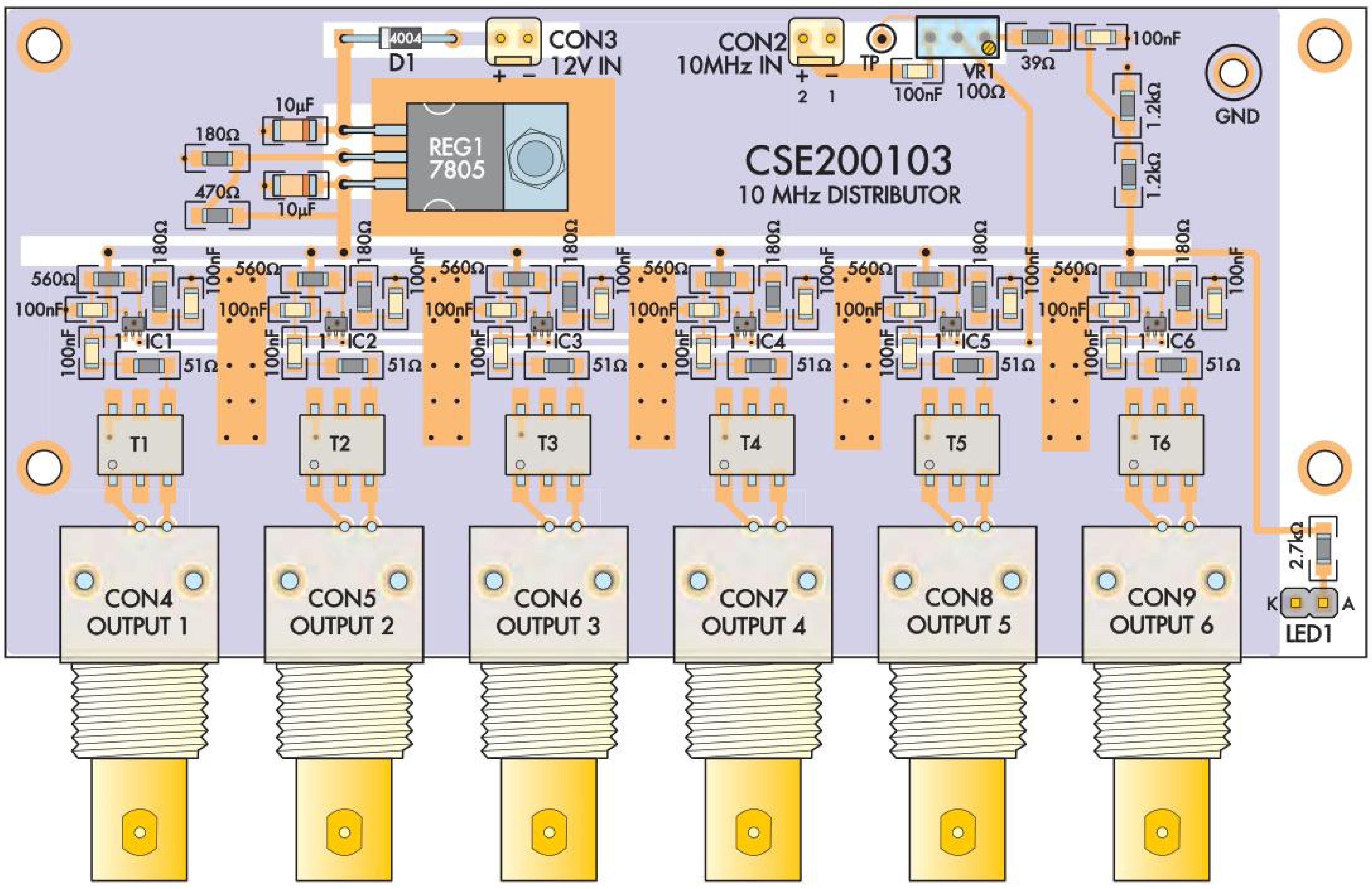
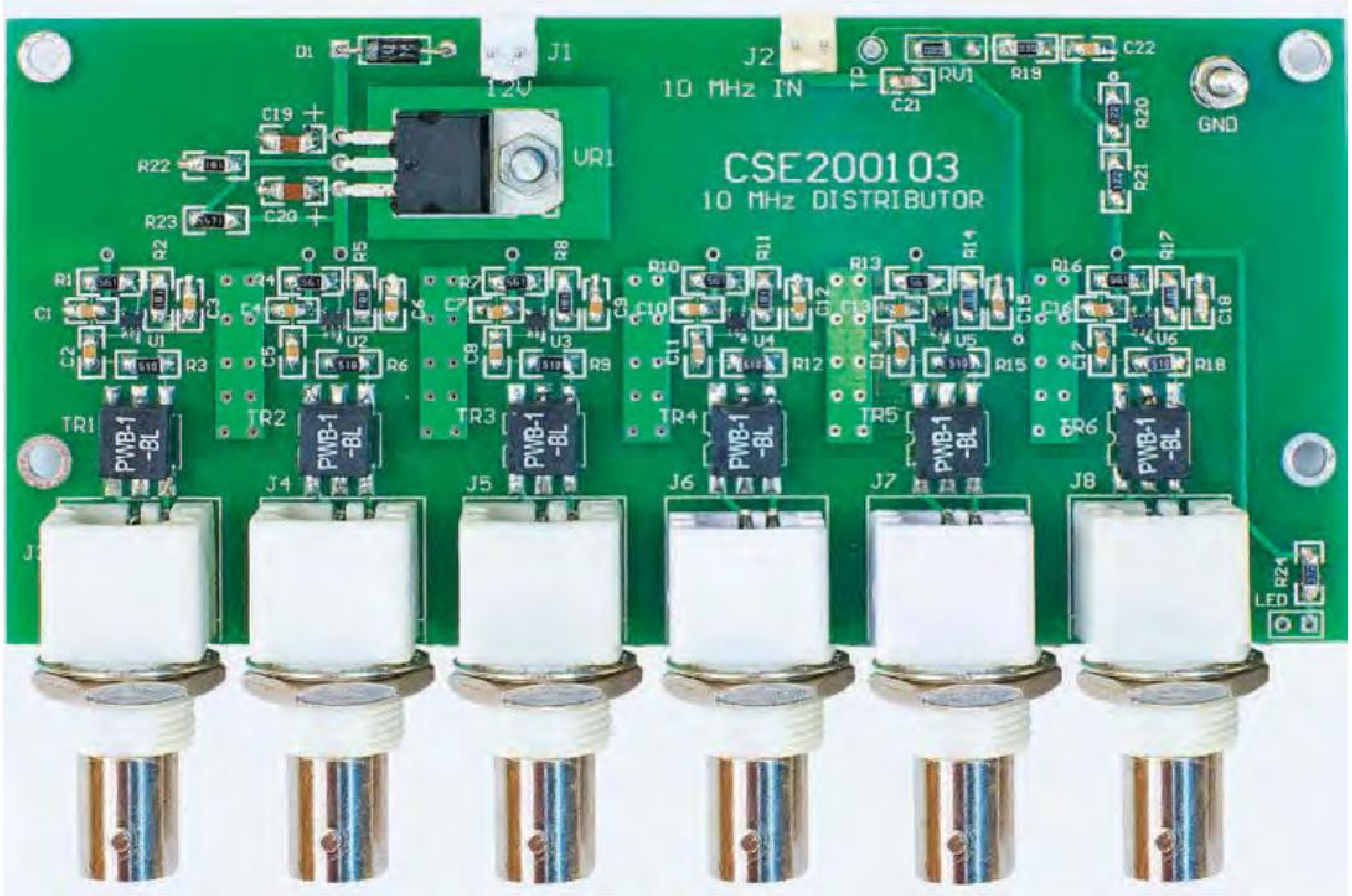


Fig.4: use this PCB overlay diagram and the photo below as a guide during assembly. Most of the components are SMDs, with the op amps being in small 5-pin SOT-23 packages and the RF transformers in larger six-pin plastic packages. The only components which could be fitted with the wrong orientation are diode D1 and LED1.



Through-hole parts

Solder diode D1 in the usual manner, ensuring it is oriented as shown in Fig.4. Then bend the leads of REG1 down so that they fit through their pads with the tab hole lining up with the PCB mounting hole. Attach it using an M3 screw and nut, and do it up tight before soldering and trimming the leads.

Follow with headers CON2 and CON3, oriented as shown, then trimpot VR1. Orient VR1 with its adjustment screw on the side facing away from CON2. Then mount the six BNC sockets. They are quite bulky, so make sure they are sitting completely flat on the PCB before soldering the two signal pins and the two larger mounting posts in place.

In terms of board assembly, that just leaves LED1. We'll solder it in vertically now, but it can be bent over later to protrude through a front panel hole next to the BNC connectors. Its anode (longer) goes to the pad closest to the 2.7kΩ SMD resistor. The flat side of the lens indicates the cathode, opposite the anode. Solder it with the base of its lens 10mm above the top of the PCB and trim the leads.

Case preparation

Fit the four tapped spacers to the corner mounting holes with short machine screws and place the board in the case. Slide it so that the BNC sockets are touching the side, and measure the distance from the top of the metal surrounds to the top of the box.

If you measured from the top of the bump on the RCA socket, add 5.5mm to this measurement, otherwise, add 5mm. Then measure that far down from the top of the case on the outside, directly opposite one of the connectors, and mark the case there.

For example, if you measured 23mm on the inside, from the top of the bump, mark the outside 28.5mm from the top. Then punch that location using a hammer and nail, and drill a pilot hole there (or use a centre punch, if you have one). You should find that this hole corresponds with the centre of the BNC socket.

The connectors are mounted 3/4-inch (19mm) apart, so drill five more pilot holes at the same level, each spaced 19mm apart, corresponding to the locations of the other BNC sockets. Then drill a 3mm hole 14mm to the right of the right-most socket for the LED.

Enlarge the other six holes to 12.7mm (0.5-inch) diameter, then check that the BNC socket surrounds all fit.

Once they do, remove the nuts and washers from the BNC sockets, along with one of the tapped spacers from the PCB.

Push the BNC sockets fully through their mounting holes, then mark the location of that one hole in the base of the case. Refit that tapped spacer, remove another one and repeat until you have marked all four holes. Then drill them out to 3mm.

Decide where you want to mount the input socket and DC power socket, then punch and drill those locations large enough to fit the connectors. Clean up the case and deburr all the holes.

You can now mount the PCB in the case using four machine screws through the base and into the tapped spacers, and refit the BNC socket washers and nuts. Stick the rubber feet onto the bottom of the case, in the corners.

Measure the distance from the two chassis-mount connectors to their corresponding headers on the board, then cut a generous length of shielded cable to suit both. Strip back the outer sheath at each end of both cables, then separate out the shield wires and twist them together.

Attach the polarised header plug pins to the inner conductor and shield at one end of each (we recommend you crimp and solder), then push them into the plastic plug housings, referring to Fig.4 to see which side the shield braid goes to (marked '–' in both cases).

Solder one cable to the chassis-mounting BNC socket, so that the shield braid goes to the outer tab and the inner wire goes to the middle pin.

Similarly, for the DC socket, solder the shield braid to the tab connecting to the outer barrel of the connector when it's plugged in, and the inner wire to the tab connecting to the tip.

Don't be trapped by the fact that many sockets have a third switched negative tab. It's initially connected to the outside of the barrel but is disconnected when a plug is inserted.

Check for continuity between the tab and the outside of the barrel when the plug is inserted.

Plug the polarised headers into the correct sockets and bend LED1's leads so that the lens pokes through the hole in the front panel without shorting its leads together.

Parts list – Signal Distributor

1 double-sided PCB coded CSE200103, 125.5 x 60mm
1 diecast aluminium enclosure with room for the PCB and chassis connectors [eg, Jaycar Cat HB5046, 171 x 121 x 55mm
6 Coilcraft PWB-1-BLC 425MHz transformers, SMD-6 package (T1-T6) [element14]
1 chassis-mount BNC socket (CON1)
2 2-pin polarised headers and matching plugs (CON2,CON3)
6 PCB-mount BNC sockets (CON4-9)
1 chassis-mount DC barrel connector (CON10)
1 12V DC 150mA+ plugpack or other power supply
9 M3 x 6mm panhead machine screws
1 M3 hex nut
4 9mm tapped spacers
1 500mm of single-core shielded cable
4 stick-on rubber feet

Semiconductors
6 MAX4450EXK+T 210MHz op amps, SC-70-5 (IC1-IC6)
1 7805 5V 1A linear regulator, TO-220 (REG1)
1 3mm LED (LED1)

Capacitors
2 10µF 16V X5R ceramic, SMD 3216/1206 size
20 100nF 16V X7R ceramic, SMD 2012/0805 size

Resistors (all 1% SMD 3216/1206 size)
1 2.7kΩ 2 1.2kΩ 6 560Ω 1 470Ω
7 180Ω 6 51Ω 1 39Ω
1 100Ω multi-turn vertical trimpot (VR1) [eg, Jaycar Cat RT4640]

Testing

You can now apply power via the DC socket and check that LED1 lights up. If it doesn't, check that you've wired up the DC socket to the board correctly, so that there is continuity from the centre pin of the DC socket to the anode of D1 (opposite the striped end). Also check that D1 and LED1 have been fitted with the correct polarity.

If it still doesn't work, your power supply may be a tip-negative type. In that case, you will have to swap the pins going into the plug for CON3.

Now feed a signal into the input and use a scope or frequency counter to check that the correct frequency signal appears at each output. Assuming you have a scope or some other means of measuring the output amplitude, adjust VR1 for +10dBm which is around 0.7V RMS or 2V peak-to-peak. You could adjust for a different level if needed. Don't forget to apply a 50Ω load when making these adjustments.

Given that each buffer provides four times gain, it should be possible to get a +10dBm output with an input signal as low as +4dBm (350mV RMS or 1V peak-to-peak).

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- Food-safe operation – in particular, liquid dispensing from a small, cooled storage tank to a customer vessel
- Overall systems integration
- Web connected
- Able to take digital payment – for example, chip and pin, contactless payment and Apple Pay

The mechanical engineering side of the project is relatively straightforward and is likely to involve little more than a cooler, a pump, some solenoid valves, a few system monitoring sensors (flow/pressure/temperature) and connecting plumbing. However, understanding and appreciation of the engineering requirements of handling food served to the public is critical.

At this stage the design is open-ended, so it is not tied to a particular microcontroller platform. The machine will not be expected to accept traditional cash.

If this sounds like your kind of challenge then please email me at: **iancrosby668@gmail.com**

If you feel able to complete most but not all of the above then do not be put off, just let me know what you can but also cannot do.

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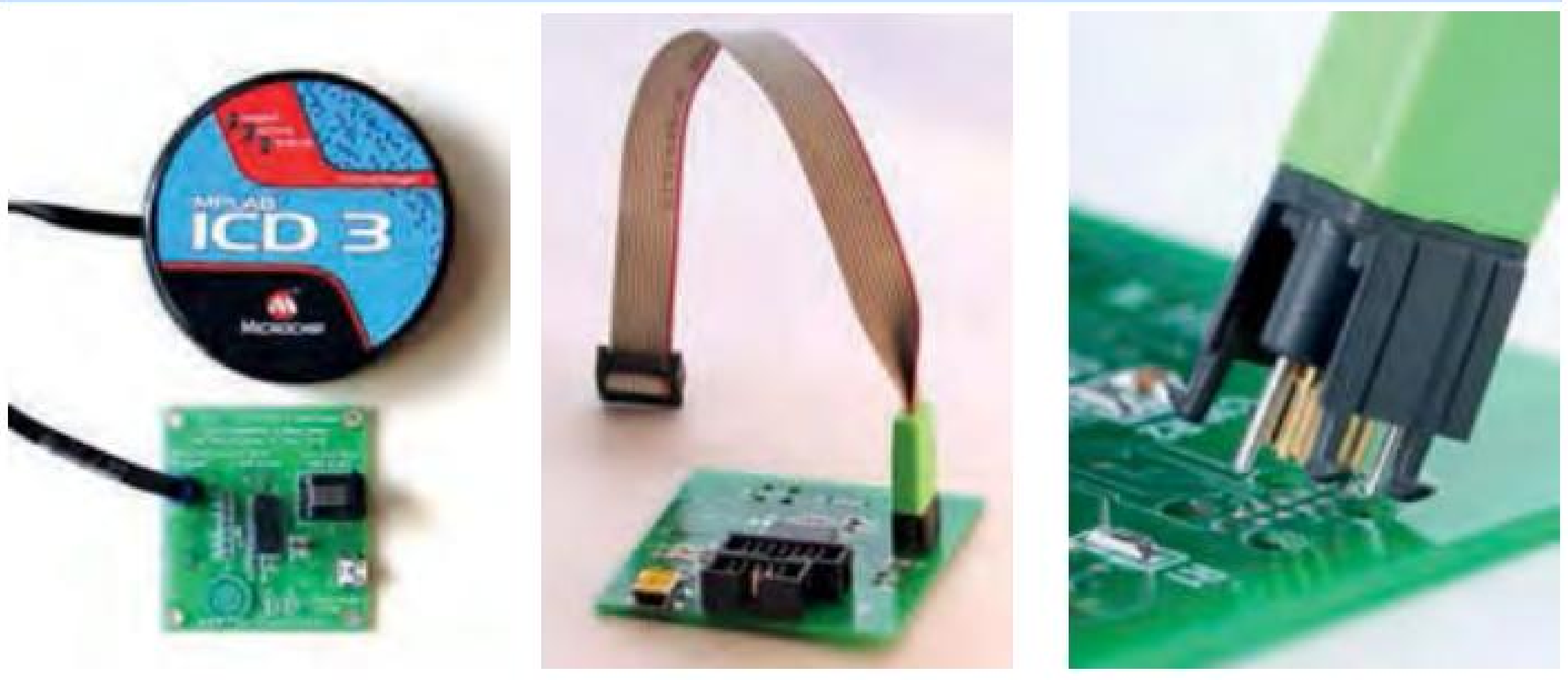

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KickStart

by Mike Tooley

Part 2: Getting started with RFID – working with cards and tags

Our occasional *KickStart* series aims to show readers how to use readily available low-cost components and devices to solve a wide range of common problems in the shortest possible time. Each of the examples and projects can be completed in no more than a couple of hours using off-the-shelf parts. As well as briefly explaining the underlying principles and technology used, the series will provide you with a variety of representative solutions and examples, along with just enough information to be able to adapt and extend them for their own use.

This second instalment shows you how to use low-cost RFID devices and, in keeping with the *KickStart* philosophy, we've provided sufficient information – including some simple Arduino sketches – for you to be able to incorporate RFID into your own projects.

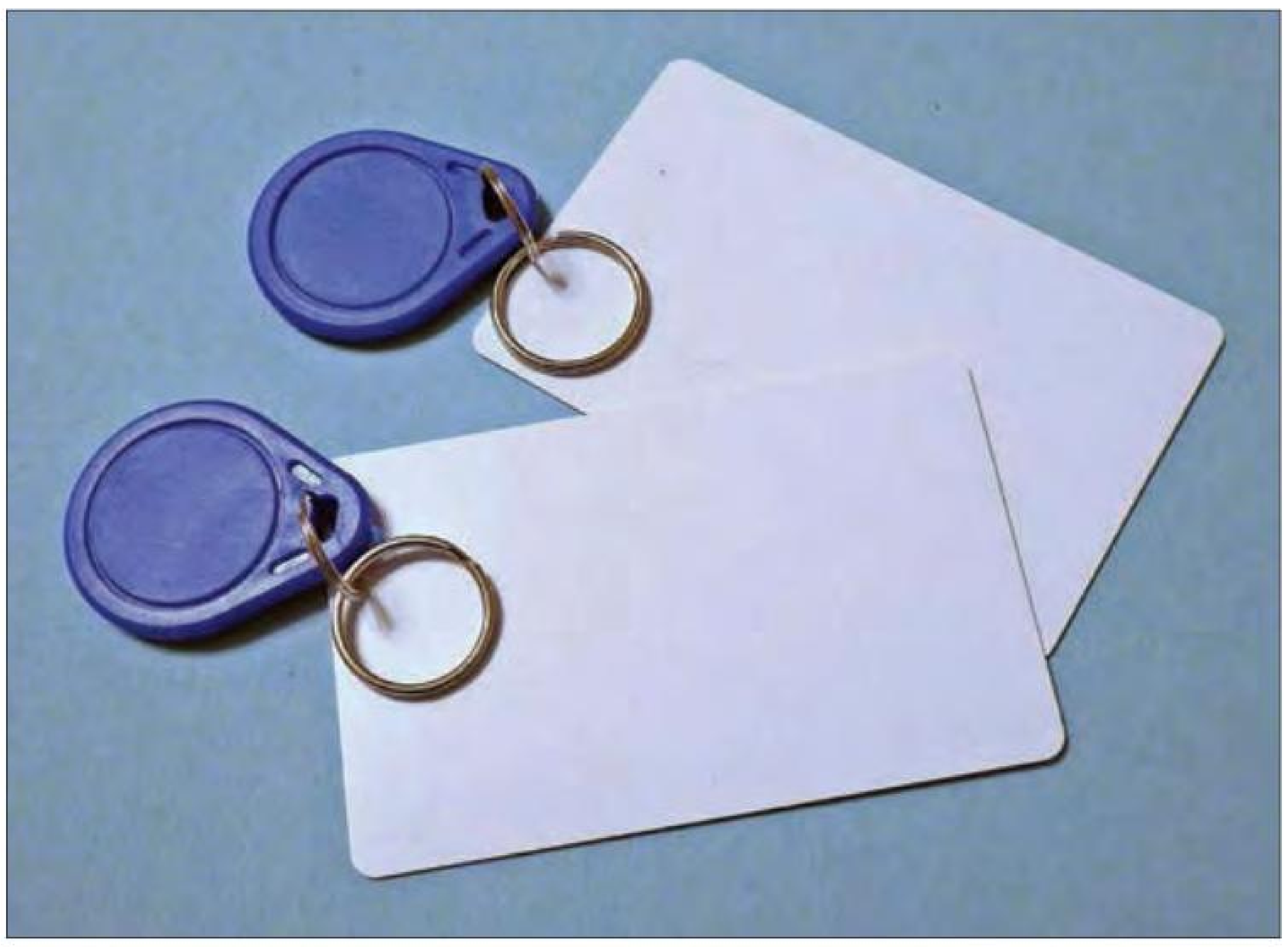


Fig.2.1. Widely available RFID tags (left) and cards (right).

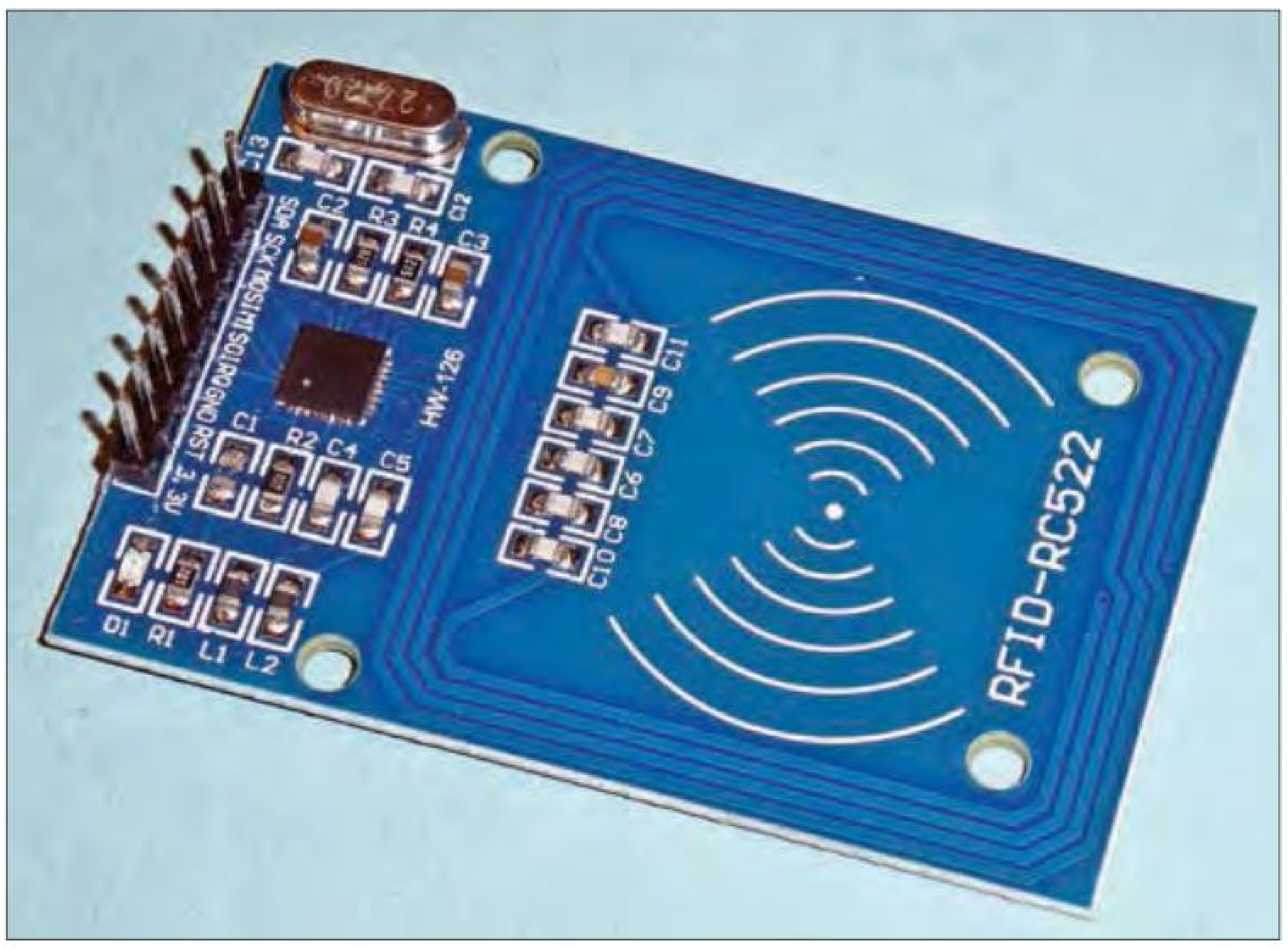


Fig.2.2. A popular MFRC522-based RFID module.

Radio Frequency IDentification (RFID) is a technology that allows stored data to be interrogated by radio without physical contact. An RFID system comprises two basic components: an RFID card or tag, and an RFID reader. The latter device is fitted with a small antenna and the tags or cards can also contain their own miniature antennas. The two devices communicate wirelessly by means of high-frequency radio signals. The signal returned to the reader is modulated with data stored in non-volatile memory within the card or tag. The received and demodulated data stream is then passed from the reader to a host computer or a microcontroller system.

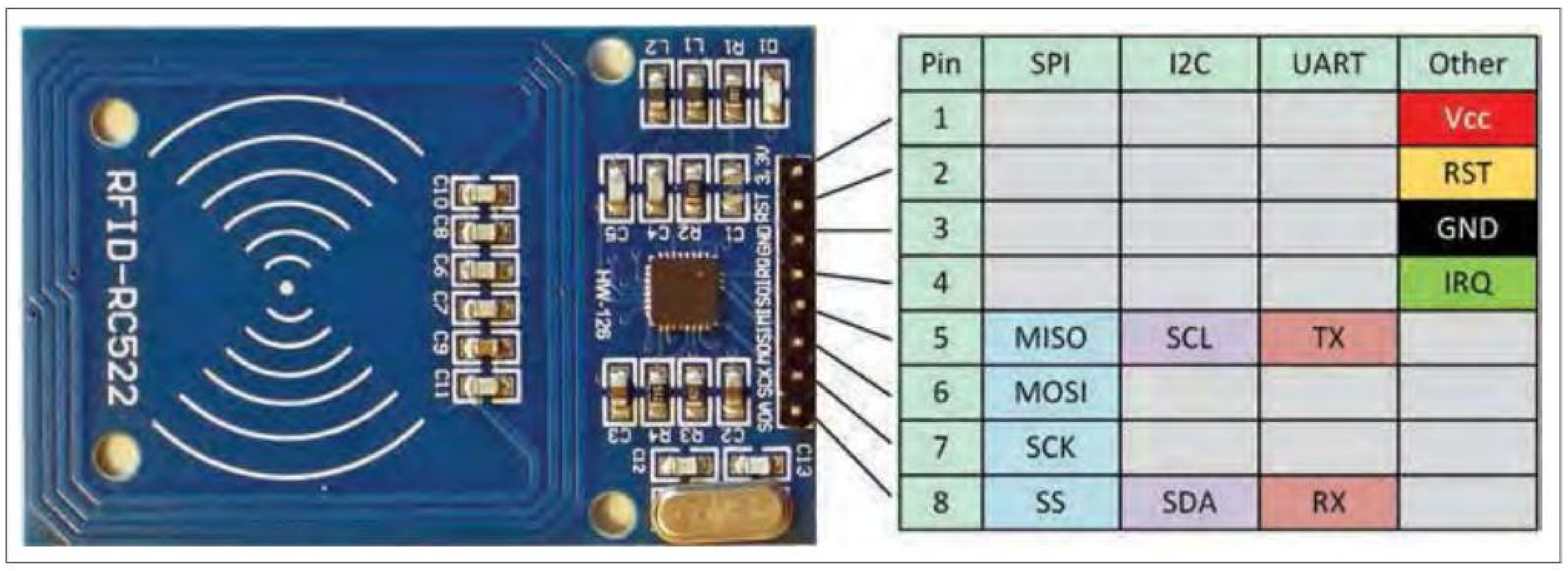
Low-cost plastic enclosures protect cards and tags from their external environment. Popular cards (such as those manufactured by NXP) conform to a standard credit-card size, while tags are often designed to be used with key rings.

RFID systems can be either passive or active. Passive RFID systems are smaller and cheaper than active systems because there is no need for the card or tag to incorporate its own power source. Active systems can operate over greater distances but are more complex and expensive than their passive counterparts. Note that passive cards and tags must derive their power from a reader (which must be present and in close proximity) before data can be returned to the reader.

The widely available NXP MIFARE Classic RFID card is available at low-cost (around 25p when purchased in quantity) and it measures 85.5 × 54mm (ISO credit card size). The most widely available cards incorporate 1KB of non-volatile memory and the PVC laminated surface can be printed on using a desktop photo ID printer (note that they are not compatible with standard inkjet printers). Data storage time is quoted as, 'a minimum of ten years'.

What can you do with RFID?

In recent years, low-cost modules have become available to the enthusiast and hobbyist making it possible to use them in a wide range of applications. The reading and writing is achieved using a compact low-power wireless transceiver which,



Pin	SPI	I2C	UART	Other
1				Vcc
2				RST
3				GND
4				IRQ
5	MISO	SCL	TX	
6	MOSI			
7	SCK			
8	SS	SDA	RX	

Fig.2.3. Pin assignment for the MFRC522-based RFID module.

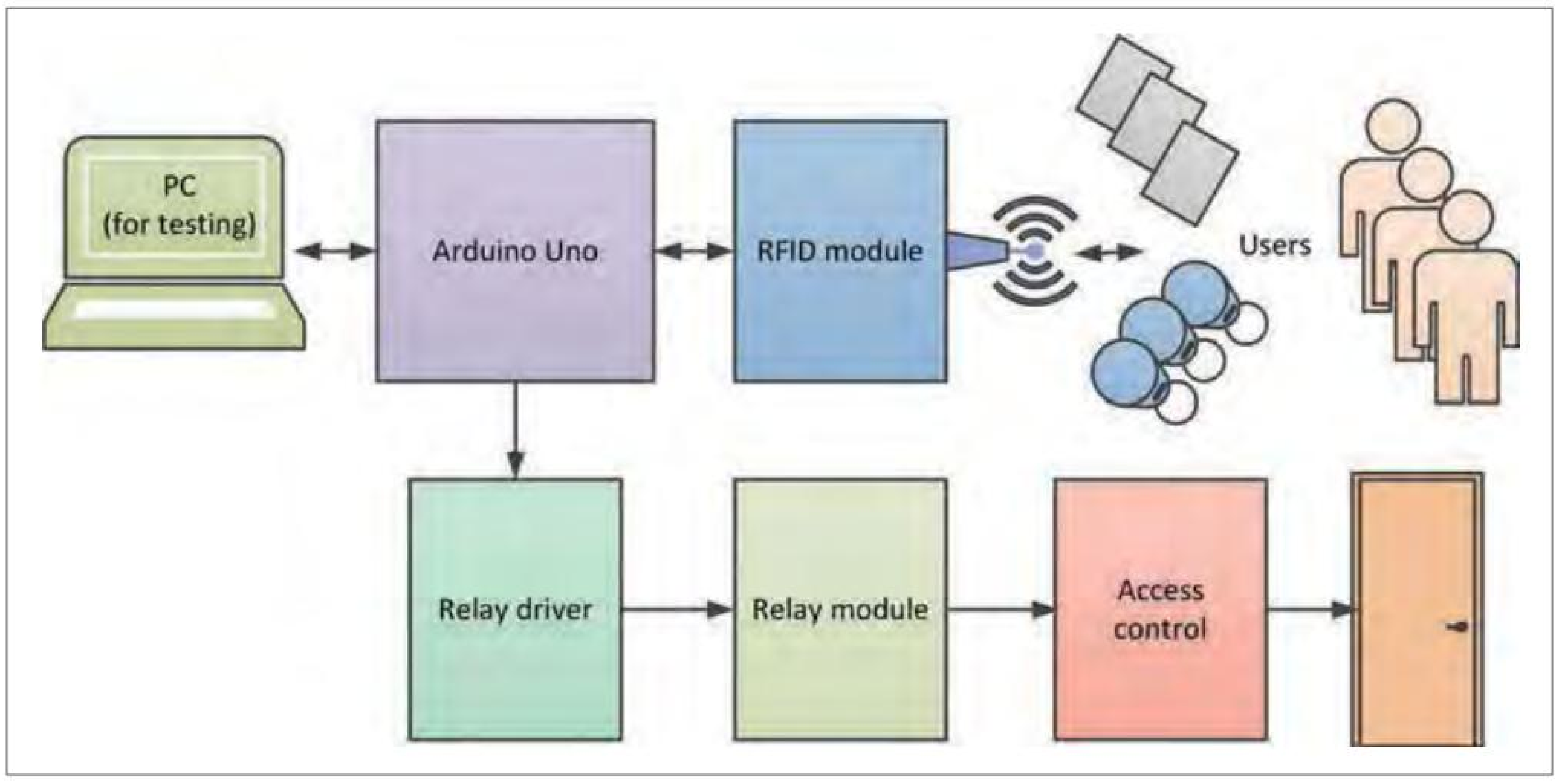


Fig.2.4. A simple RFID application based on an RC522 RFID module and an Arduino Uno microcontroller.

together with a modest microcontroller chip, allows you to read data from and write data to cards and tags (see Fig.2.1).

Depending on the envisaged application, an RFID reader can be fixed or portable. In use, the reader is placed close to the card or tag and held briefly while the data is being read. Note that only one card or tag can be read at a time. Furthermore, care must be taken to ensure that communication between the reader and tag is not compromised and the data being read is valid. Commercial applications of RFID include asset tracking, inventory management, personnel tracking, access control, maintenance, counterfeit prevention, and supply chain management. When compared with barcode scanning, a significant advantage of RFID technology is that there is no need for precise alignment because the wireless data stream can be read from a tag or card in random orientation.

An RC-522 RFID module

A commonly available low-cost RC-522 RFID module is shown in Fig.2.2. This handy device will provide you with a means of adding RFID facilities to any SPI, I^{2}C or UART-based microcontroller. The RFID module is based on an MFRC522 chip from NXP. This device is a highly integrated reader/writer designed to support contactless communication conforming with relevant ISO/IEC standards.

The chip's internal transmitter provides sufficient output to drive a reader/writer antenna without the need for any additional active circuitry. The internal receiver incorporates circuitry for demodulating and decoding 64-byte signal blocks from compatible cards and transponders, and its internal logic manages framing and error detection (parity and CRC) functionality. Speeds of up to 848kBd (kilobaud) are supported in both directions at an operating frequency within the high-frequency (HF) range at 13.56MHz.

To ensure versatility, the MFRC522 provides support for three different host interfaces:

- Serial Peripheral Interface (SPI) at up to 10Mbit/s
- I^{2}C-bus interface (at up to 400kBd in fast mode and up to 3,400kBd in high-speed mode)
- Serial UART (similar to RS232 but with voltage levels dependant on the supply voltage).

The MFRC522 chip's internal clock operates at 27.12MHz and the chip requires a supply voltage of between 2.5V and 3.3V at typically up to 50mA. In applications where power consumption

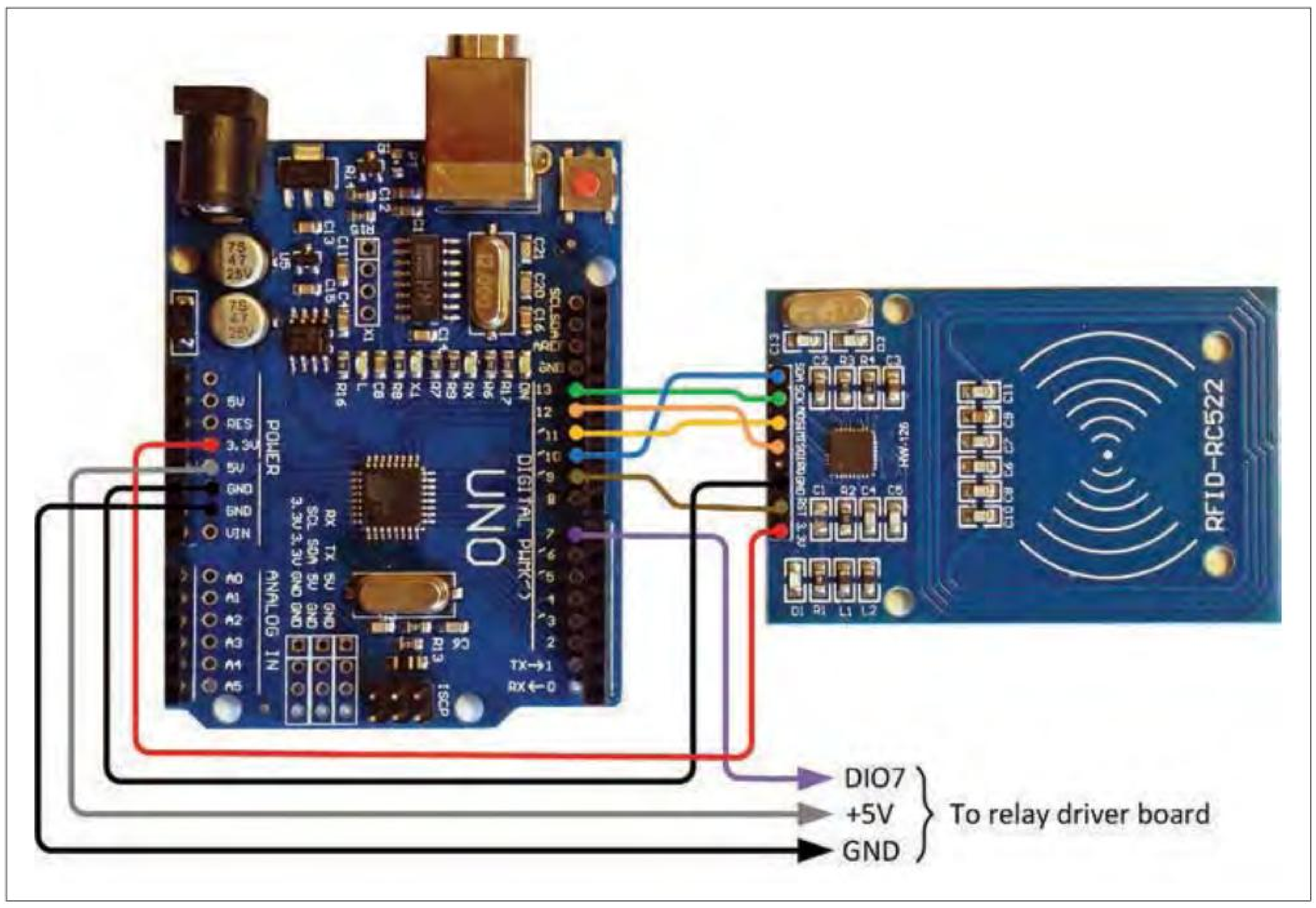


Fig.2.5. Wiring for the simple RFID application.

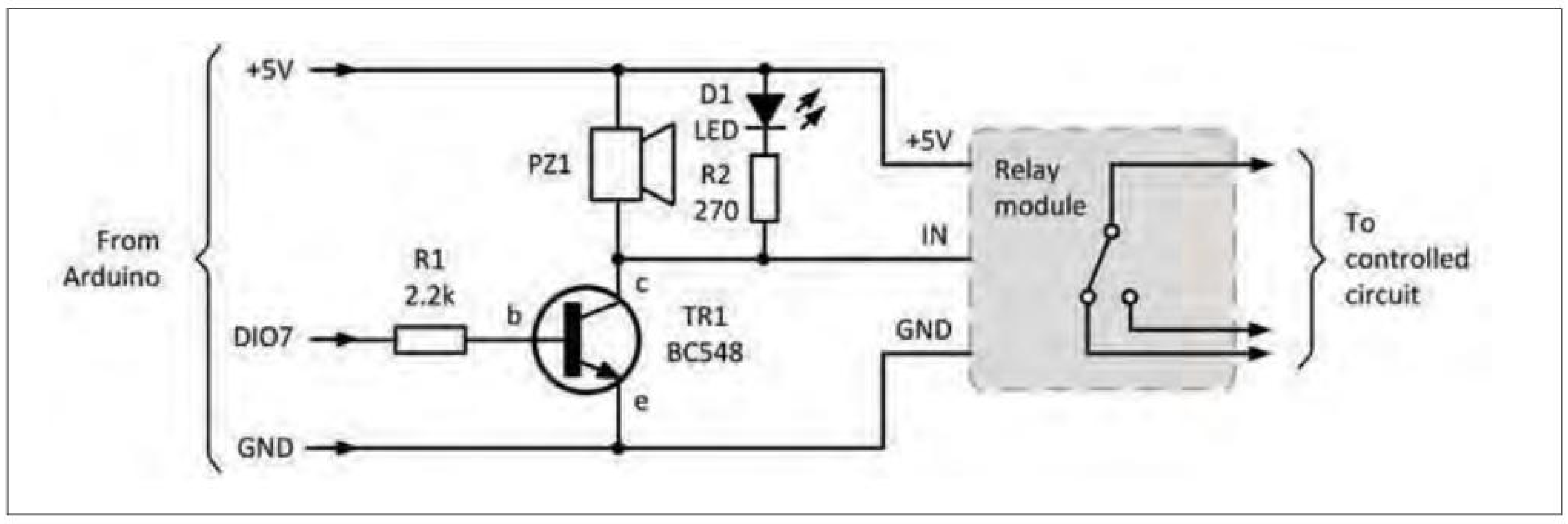


Fig.2.6. Interstage piezo sounder driver circuit.

Table 2.1 Wiring an RC522 RFID module with the Uno's SPI interface

RC522 module	Arduino Uno	Wiring colour (see Fig.2.5)	Notes
3.3V	3.3V	Red	3.3V power
RST	DIO9	Brown	Reset line
GND	GND	Black	Common ground / 0V
IRQ	N/C		Not used
MISO	DIO12	Orange	SPI data from the Uno to the RC522
MOSI	DIO11	Yellow	SPI data from the RC522 to the Uno
SCLK	DIO13	Green	Serial clock for SPI
SDA	DIO10	Blue	SPI SS chip enable

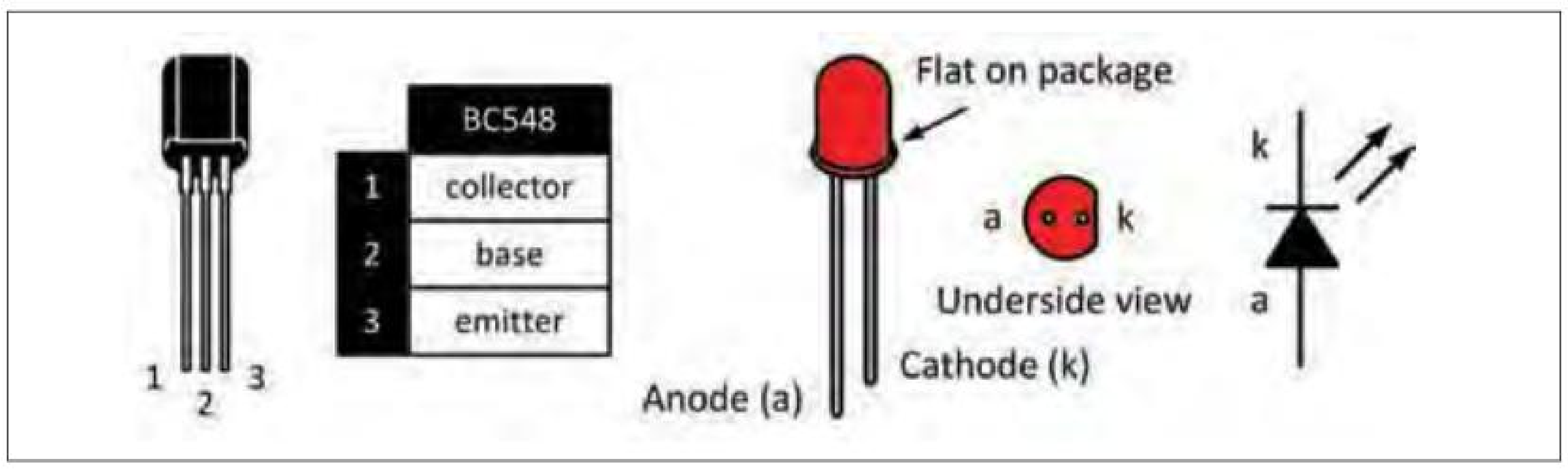


Fig.2.7. Semiconductor pin connections for Fig.2.6.

must be minimised, it is possible to use the RC-522 in low-power standby mode to reduce battery current. In this mode, the module requires a mere 10µA of supply current. A signal applied to the IRQ pin can then be used to wake the module ready for normal read/write operations.

A simple RFID application

To give you an idea of just how easy it is to incorporate RFID in your own projects, here's a simple example in the form of a basic RFID entry control application based on an RFID-RC522 module and an Arduino Uno, as shown in Fig.2.4.

The wiring from the RFID module to the Arduino is shown in Fig.2.5. The required connections based on the Uno's SPI interface are shown in Table 2.1.

An extra driver stage is needed to supply adequate current to the piezoelectric sounder (thus reducing the load on the Arduino's digital output port). The circuit of the interstage driver is shown in Fig.2.6, and the semiconductor pin connections are shown in Fig.2.7.

Testing the RFID application

Since both audible and visual indications are provided by the interstage relay driver, our sample RFID system can be tested *without* the external relay module and door electronics. The external relay module can be a low-cost module (see Table 2.2, *Going Further*) and should be suitably rated. Typical relay boards are shown in Fig.2.8 and Fig.2.9. The relay board in Fig.2.8 is rated for switching AC of up to 250V at 10A and DC of up to 30V at 10A. The solid-state relay board shown in Fig.2.9 is suitable for AC operation up to 240V AC at 2A. Both of these boards require a 5V supply of around 150mA and both are available at very modest cost from on-line suppliers (see *Going Further*).

Coding the RFID module

Coding is straightforward using the Arduino IDE (see *Going Further*) but will require the appropriate library

Listing 2.1: This code (PE_KS_2-1.ino) reads the data stored on an RFID card or tag when held close to the reader.

```
// MRFC522 Card Infodump V1.1
// Reads card or tag UID and dumps contents of memory

// Include the library routines
#include <SPI.h>
#include <MFRC522.h>

// Define the pins
#define RST_PIN 9
#define SS_PIN  10

// Create an instance of the MFRC522
MFRC522 mfrc522(SS_PIN, RST_PIN);

// Set-up code
void setup() {
   Serial.begin(9600);     // Initialize serial port communication
   SPI.begin();            // Initialise the SPI bus
   mfrc522.PCD_Init();     // Initialise the MFRC522
   Serial.println("Card Information Dump V1.1a");
   Serial.println("Place the card or tag close to the reader and
      wait until all data is read ...");
}

void loop() {
   byte i;

   // Is a card detected?
   if (mfrc522.PICC_IsNewCardPresent())
   {

      // Can the serial number be read?
      if (mfrc522.PICC_ReadCardSerial())
      {
         Serial.println();
         Serial.print("Card detected : ");
         mfrc522.PICC_DumpToSerial(&(mfrc522.uid));

      }
   }
}
```

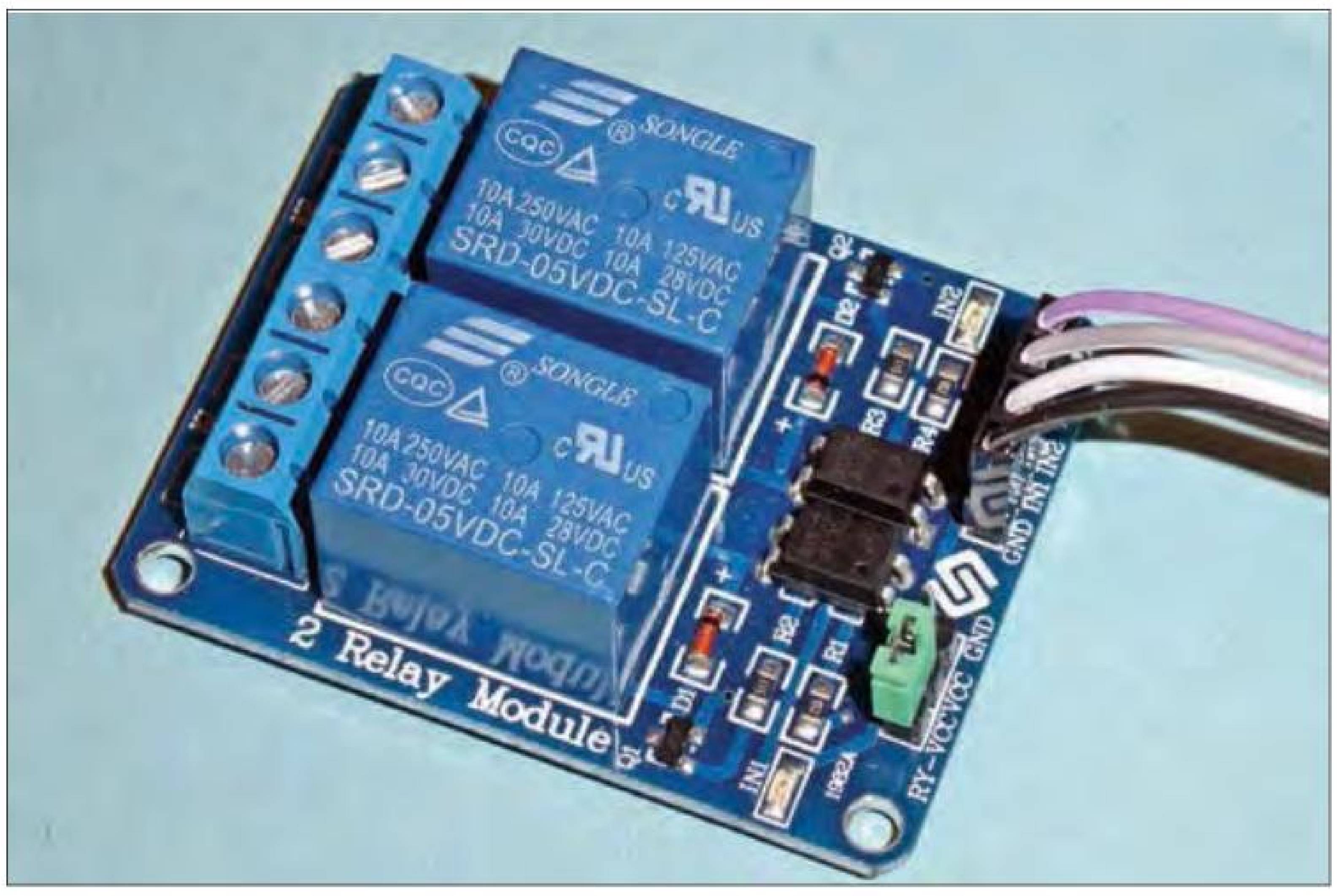


Fig.2.8. Off-the-shelf relay board.

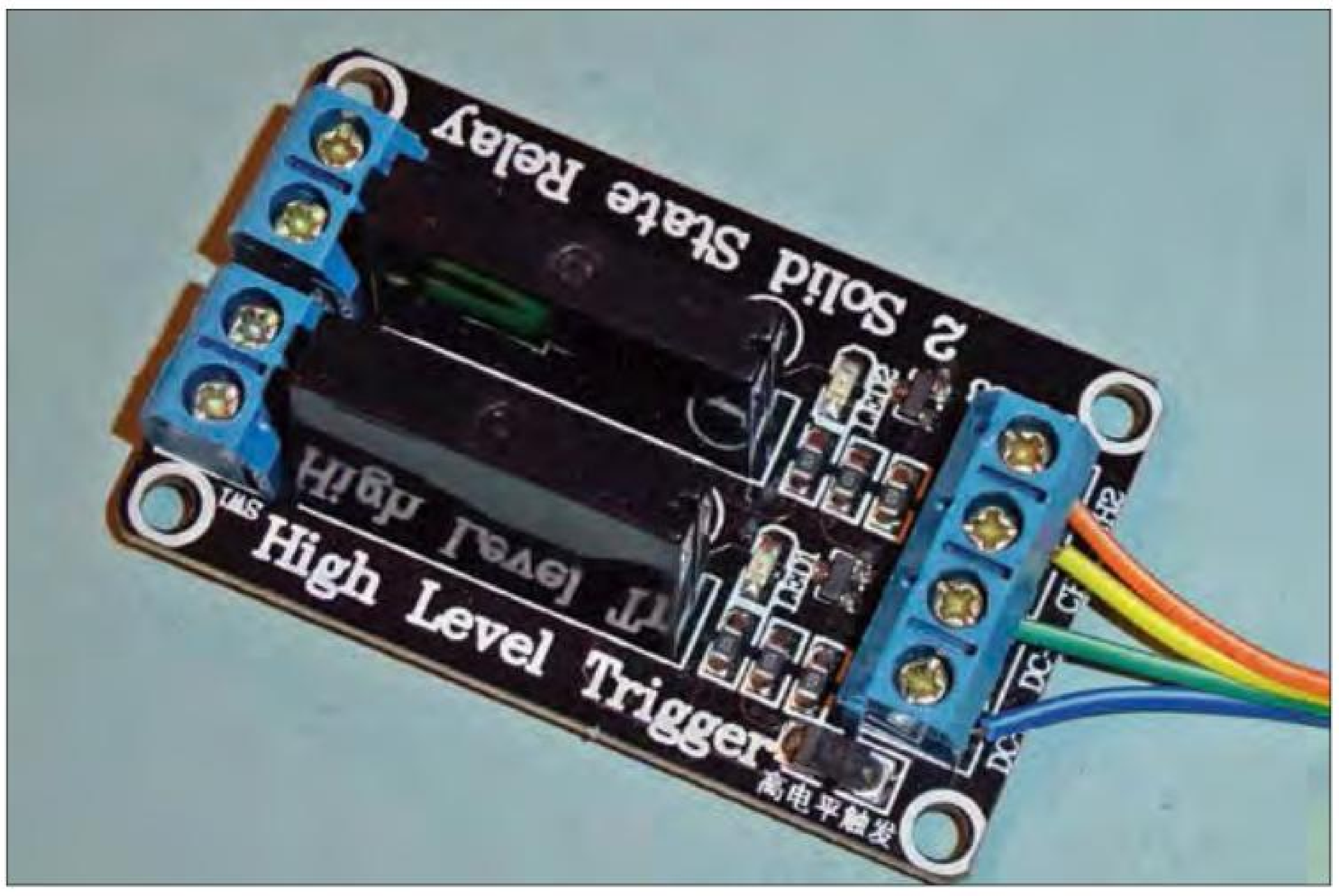
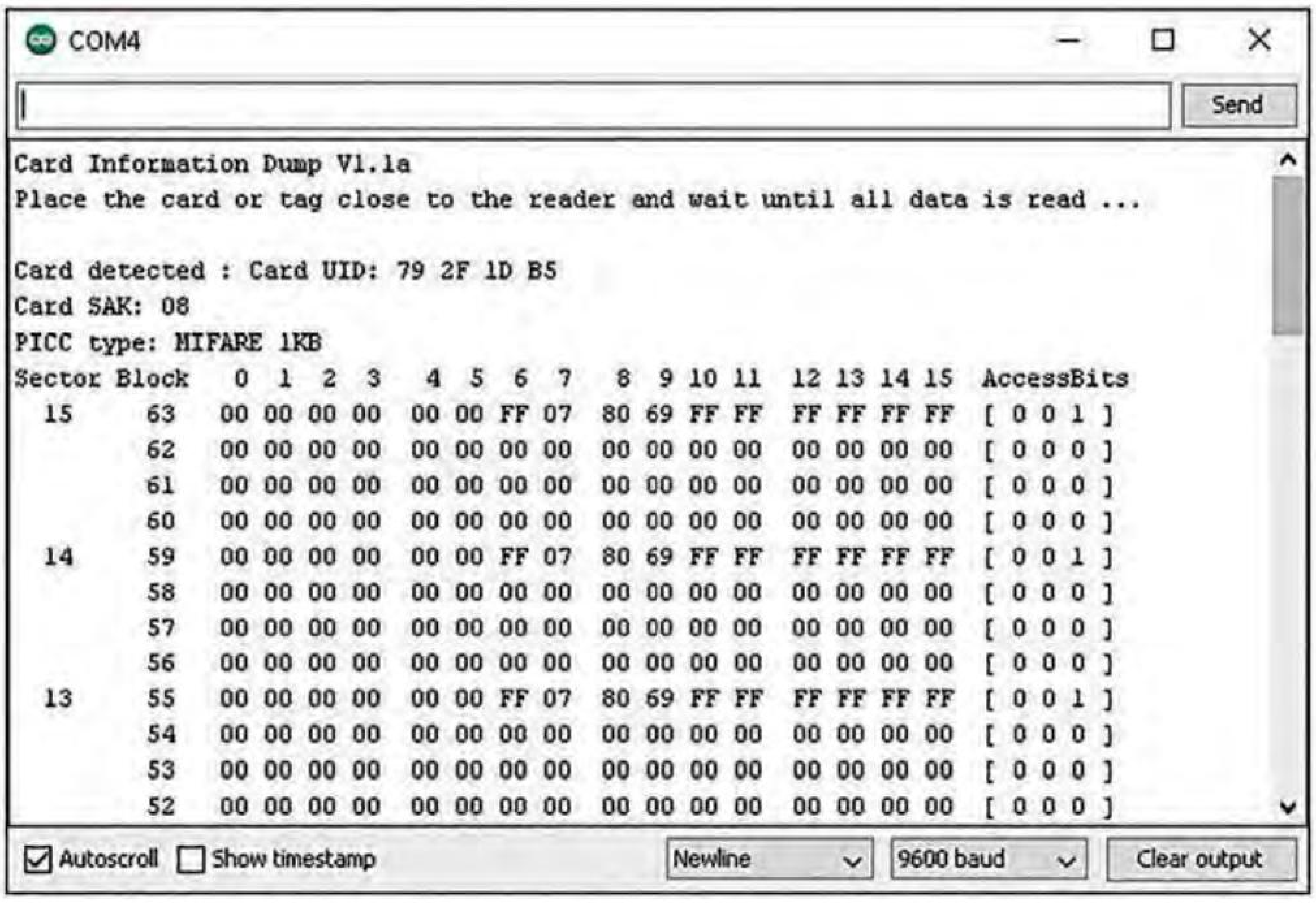


Fig.2.9. Solid-state alternative relay board.



```
Card Information Dump V1.1a
Place the card or tag close to the reader and wait until all data is read ...

Card detected : Card UID: 79 2F 1D B5
Card SAK: 08
PICC type: MIFARE 1KB
Sector Block   0  1  2  3   4  5  6  7   8  9 10 11  12 13 14 15  AccessBits
  15     63   00 00 00 00  00 00 FF 07  80 69 FF FF  FF FF FF FF  [ 0 0 1 ]
         62   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
         61   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
         60   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
  14     59   00 00 00 00  00 00 FF 07  80 69 FF FF  FF FF FF FF  [ 0 0 1 ]
         58   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
         57   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
         56   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
  13     55   00 00 00 00  00 00 FF 07  80 69 FF FF  FF FF FF FF  [ 0 0 1 ]
         54   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
         53   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
         52   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00  [ 0 0 0 ]
```

Fig.2.10. The data stored on a card or tag can be read using code like that in Listing 2.1.

which can be downloaded from the web. Start the Arduino IDE and select Tools and then Manage Libraries. From the Library Manager enter 'miguelbalboa' (the library's author) in the search box. You should then see a library called: `MFRC522-spi-i2c-uart-async`

Select the file and click on Install. The new library file will then be downloaded and installed, and the library list will be updated accordingly. Click on Close and return to the main IDE window. Enter the sample code from Listing 2.1 (available for download from the April 2021 page of the *PE* website).

831D3F03
B5BB3F03

Fig.2.11. RFID tags labelled with unique 64-bit identifiers.

Make sure you save the file when you have finished editing. Next, ensure that you have the correct board type selected (ie, Arduino Uno) and also that the correct serial port has been selected (note that both of these options are selected from the IDE's Tools menu). Finally, select Sketch from the main menu and Verify/Compile and Upload.

Table 2.2: Going Further with RFID cards and tags, and the Arduino Uno

Topic	Source	Notes
RFID technology	Atlas RFID Store have a useful beginners' guide to RFID: **http://bit.ly/pe-apr21-ks2-1** Another general introduction is at: **http://bit.ly/pe-apr21-ks2-2** For innovative 13.6MHz RFID tags and applications: **http://bit.ly/pe-apr21-ks2-3**	
MFRC522 chip	The MFRC522 data sheets can be downloaded from NXP at: **http://bit.ly/pe-apr21-ks2-4**	
RC-522 RFID module	RC-522 modules are available from several suppliers, including: HobbyTronics at: **http://bit.ly/pe-apr21-ks2-5** AZ-Delivery at: **http://bit.ly/pe-apr21-ks2-6**	Low-cost kits are available which include readers, tags and cards. Cards and tags can be purchased very cheaply in large quantities.
Arduino Uno	A detailed introduction to the hardware and software of the Arduino Uno can be found in *PE's Electronics Teach-In 8*.	**http://bit.ly/pe-apr21-ks2-7**
Arduino IDE	For a useful introduction and relevant theory see *Part 1* of *Electronics Teach-In 8*. The latest version of the Arduino IDE can be downloaded from: **https://www.arduino.cc/en/software** Versions are available for Windows Linux and macOS. The current IDE version is 1.8.13.	**http://bit.ly/pe-apr21-ks2-7**
Interfacing	The author's book, *Electronic Circuits: Fundamentals and Applications* (5th Ed, 2020, Routledge) provides a general introduction to microcontroller interfacing (Ch.15) and the Arduino Uno (Ch.19).	
RFID library	The RC522 Arduino library can be downloaded from GitHub at: **https://github.com/miguelbalboa/rfid**	The library can be downloaded using the IDE's built-in library manager (which is supported). Note that this library works with Arduino IDE 1.6 (and later) but previous IDE versions are not supported (causing potential compiler errors).
Relay boards	Relay boards can be purchased at low cost from many suppliers, including: AZ-Delivery, HobbyTronics, CPC/Farnell, Mouser, RS and online suppliers.	Relay boards can be purchased with one, two, four or eight relays, the latter is ideal for multi-channel operation.

Sample code listings

Our two sample listings show the simple code necessary to test the application. Listing 2.1 can be used to check a card's unique identifier (UID) and view the stored data. Listing 2.2 provides an example of how the reader can be used in a simple access control system (see Fig.2.4). Note that it is possible to write data as well as read data and this feature makes it possible to store and subsequently update information on a card or tag. Several useful and liberally commented examples are provided in Miguel Balboa's library file.

The data returned from Listing 2.2 reveals the UID, which in this case is 79 2F 1D B5 (see Fig.2.10). Data is organised in blocks and sectors. Each block comprises 64 bytes of data and there are 16 sectors on the 1K MIFARE tag. The UID is contained in the first four bytes in Sector 0, Block 0 (not shown in Fig.2.10, which only shows the last three data blocks). Note that the UID is written during manufacture and cannot normally be changed (for test purposes I found it useful to write a tag's UID on the tag, as shown in Fig.2.11). Finally, Fig.2.12 shows the frequency spectrum of the signal produced by the RFID application. Note that the signal is centred on approximately 13.56MHz and it occupies a bandwidth of around 100kHz.

Going further

Table 2.2 lists sources to help you locate components, information that will help you with your own RFID applications and links to useful background reading.

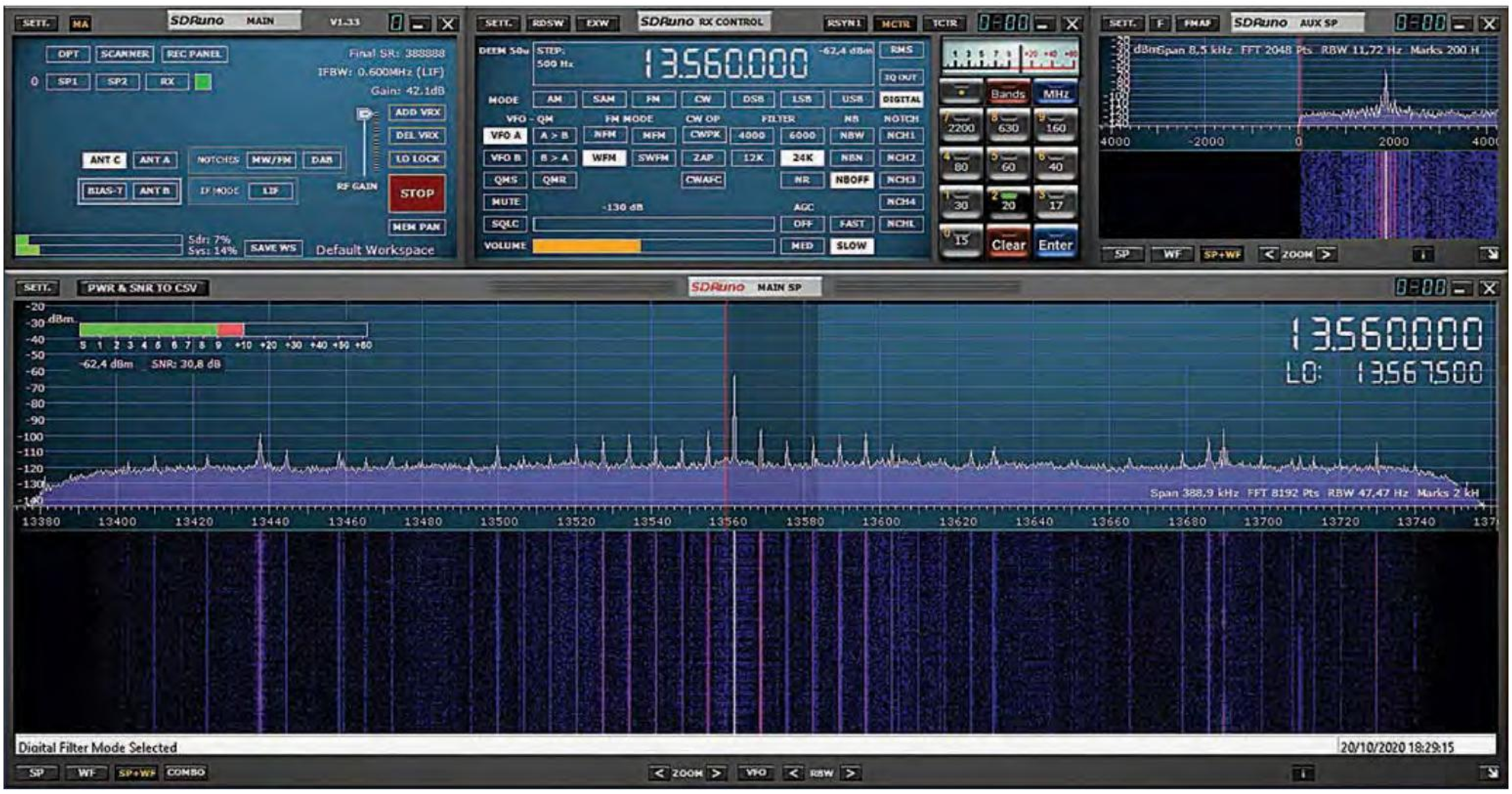

SDRuno MAIN V1.33
Final SR: 388888
IFBW: 0.600MHz (LIF)
Gain: 42.1dB
STOP
Default Workspace
SDRuno RX CONTROL
13.560.000
-62.4 dBm
SDRuno AUX SP
Span 8.5 kHz FFT 2048 Pts RBW 11.72 Hz Marks 200 H
SDRuno MAIN SP
-62.4 dBm SNR: 30.8 dB
13.560.000
LO: 13.567.500
Span 388.9 kHz FFT 8192 Pts RBW 47.47 Hz Marks 2 kH
13380
13400
13420
13440
13460
13480
13500
13520
13540
13560
13580
13600
13620
13640
13660
13680
13700
13720
13740
Digital Filter Mode Selected
20/10/2020 18:29:15

Fig.2.12. Spectral analysis of the 13.56MHz RFID signal.

Teach-In 8 CD-ROM
Exploring the Arduino

This CD-ROM version of the exciting and popular *Teach-In 8* series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. *Teach-In 8* provides a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle wirelessly or via the Internet. *Teach-In 8* is based around a series of practical projects with plenty of information for customisation. The projects can be combined together in many different ways in order to build more complex systems that can be used to solve a wide variety of home automation and environmental monitoring problems. The series includes topics such as RF technology, wireless networking and remote web access.

PLUS: PICs and the PICkit 3 – A beginners guide

The CD-ROM also includes a bonus – an extra 12-part series based around the popular PIC microcontroller, explaining how to build PIC-based systems.

SOFTWARE

The CD-ROM contains the software for both the *Teach-In 8* and PICkit 3 series.

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Listing 2.2: The code (PE_KS_2-2.ino) checks the unique data on a card or tag and will operate the relay and piezoelectric sounder if (and only if) the correct card identifier (UID) is detected.

```
// MRFC522 Card Access Checker V2.1a
// Reads and checks card UID before activating relay and sounder

// Include the library routines
#include <SPI.h>
#include <MFRC522.h>

// Define the pins
#define RST_PIN 9
#define SS_PIN  10
#define sounder 7
#define relay 6

// Create an instance of the MFRC522
MFRC522 mfrc522(SS_PIN, RST_PIN);

// Set-up code
void setup() {
   Serial.begin(9600);        // Initialize serial port communication
   SPI.begin();               // Initialise the SPI bus
   mfrc522.PCD_Init();        // Initialise the MFRC522
   digitalWrite(relay, LOW);  // Relay non-energized
   digitalWrite(sounder, LOW);// No sound
   Serial.println("Card Access Checker V1.1a");
   Serial.println("Pleace your card or tag close to the reader ...");
}

void loop() {
   byte i;

   // Is a card detected?
   if (mfrc522.PICC_IsNewCardPresent())
   {

      // Can the serial number be read?
      if (mfrc522.PICC_ReadCardSerial())
      {

         // We have a card and its serial number so we can now format and verify the UID

         String content = "";
         for (byte i = 0; i < mfrc522.uid.size; i++)
         {
            content.concat(String(mfrc522.uid.uidByte[i] < 0x10 ? " 0" : " "));
            content.concat(String(mfrc522.uid.uidByte[i], HEX));
         }
         Serial.println();
         Serial.print("Card detected : ");

         content.toUpperCase();
         if (content.substring(1) == "83 1D 3F 03") // Change this UID to suit the card
         {
            Serial.println("Access granted");
            Serial.println();
            // Beep door opening
            digitalWrite(sounder, HIGH);
            delay(500);
            digitalWrite(sounder, LOW);
            // Activate door relay
            digitalWrite(relay, HIGH);    // Relay energized
            delay(2500);
            digitalWrite(relay, LOW);     // Relay non-energized
         }

         else   {
            Serial.println("Access denied");
            Serial.println();
            delay(2500);
         }
      }
   }
}
```

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 14

Assuming you've been following my recent columns (and, if not, why not?), you will recall my abject failure thus far to make good on my promise to implement a version of *Conway's Game of Life* (*GOL*) (**https://bit.ly/pe-jan21-cgol**) on my 12×12 ping-pong ball array (**https://bit.ly/3jMM62J**). Well, it's almost time to don our party hats and blow our party horns (**https://bit.ly/2MFwwJL**) with gusto, abandon, and – I'm sure it goes without saying (but I'll say it anyway) – aplomb, because that's what we are poised to do (… in my next column), but first let's consider...

The Big Bang

The term 'multiverse' (a.k.a. 'meta-universe') refers to a hypothetical group of multiple universes. Together, these universes are postulated to comprise everything that exists: the entirety of space, time, matter, energy, information, and the physical laws and constants that describe them. By comparison, the term 'Big Bang' refers to a part of a cosmological model of the observable part of our own particular universe from the earliest known periods through to its subsequent large-scale evolution. When I was a young lad and I first heard about the Big Bang, which kicked off *our* portion of the multiverse around 9:00am on a Wednesday morning about 13.8 billion years ago – give or take – I visualised it as a giant explosion with everything radiating out from a central location.

Later, I discovered that all of the galaxies are moving away from each other, apart from the ones that aren't, of course. By this I mean that some galaxies are close enough to each other that their local proximity and gravitational attraction (as described by Sir Isaac Newton in his law of gravitation) or distortion of the spacetime continuum (as revealed by Albert Einstein with his theory of general relativity) is sufficient to draw them together. For example, our own galaxy – the Milky Way – is scheduled to collide with our nearest neighbour – the Andromeda galaxy – about four billion years from now.

Be that as it may, when I was first exposed to all of this, my newfound knowledge caused me to visualise all of the galaxies as being dots marked on the surface of a balloon on the basis that, as a balloon is inflated, all of the dots will move apart from each other. Still later, I was introduced to a different analogy – one that involved a three-dimensional (3D) volume as opposed to a two-dimensional (2D) surface – that of a ball of bread dough with raisins mixed throughout. When the dough is baked in an oven, it will grow in size and – as a result – all of the raisins will move apart from each other.

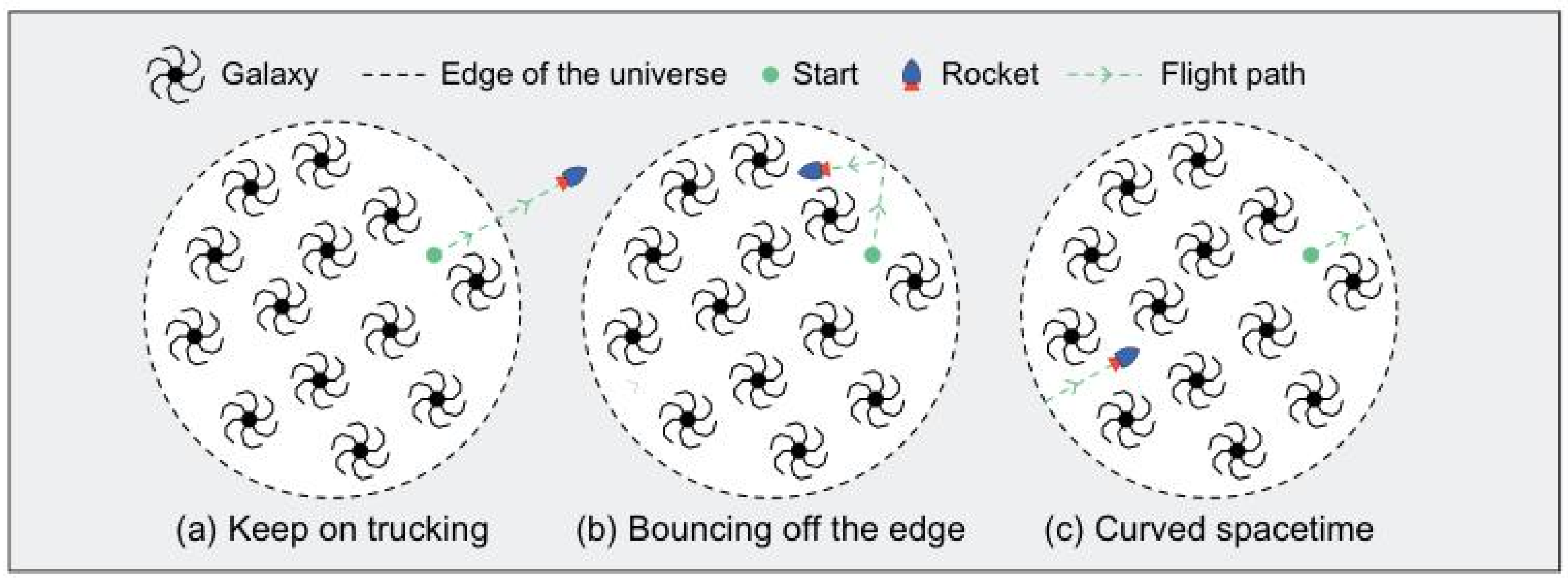


Fig.1. The edge of the universe (eeek!)

Still and all, this left me with the impression that there was a 'centre' to the Big Bang. That is, if we could determine where all of the galaxies were moving away *from*, we could backtrack and locate where everything originated. Sad to relate, this appears not to be the case, because those researchers and scientists with size-16 brains (the ones with 'go-faster' stripes painted on the sides) say, 'The galaxies are not moving *through* space, they are moving *with* space, because space itself is also *expanding*, which means the universe has no centre and everything is moving away from everything else.' I don't know about you, but I have a sneaking suspicion they are making some of this stuff up as they go along.

Don't fall off the edge!

This is where things start to get confusing because, much like Pooh, I am a bear of little brain. If the universe is expanding, what is it expanding into? Is there an 'edge' to the universe and, if so, what lies beyond? Can you imagine what it would be like to live on a planet orbiting a star that inhabits a galaxy at the very edge of the universe? Would this mean that if you were to look one way (ie, toward the centre of the Big Bang), you'd see a cornucopia of galaxies, but if you were to look the other way, all you'd see is a whole lot of nothing? If so, what sort of nothing would that be? Even if it's empty 'nothing,' that's still 'something,' isn't it? These are the types of questions that keep me awake at night. Thank goodness for the Dried Frog Pills (**https://bit.ly/3nRr6IH**), is all I can say.

Assuming for the purpose of discussion that there is, in fact, an edge to the universe. What would happen if you were born there and you decided to build a spaceship – I'd like mine to be reasonably-sized, well equipped with bathrooms, and sleek without being pretentious; perhaps a craft reminiscent of the Millennium Falcon – and you headed out into the great beyond?

Three main possibilities spring to mind. The first is that you just keep on trucking, 'Bravely going behind the beyond, behind which no man (or woman) has bravely gone behind, beyond, before,' as Captain James T. Kirk might have said in dulcet tones (Fig.1a). The second is that you somehow 'bounce off' the edge of the universe and head back towards the light (Fig.1b). The third is that the spacetime continuum is 'curved' in such a way that you eventually find yourself back where you started, which – assuming we could walk on water – we might visualise as being a tortuously time-consuming 3D hyperspatial version of taking a stroll around the Earth (Fig.1c).

As an aside, there's an old brainteaser that just popped into (what I laughingly call what's left of) my mind. In my previous *Cool Beans* (*PE*, March 2020) I posed the question, 'How long is a piece of string?' (the answer, of course, is: 'Twice as long as from the middle to one end'). Well, imagine the edge of the universe as being like a spherical shell that we could stand on, with 'down' being towards the centre. Next, suppose we have a long piece of string called A that we wrap all the way around the circumference of this shell. Finally, suppose we have a humongous collection of one-meter-tall posts that we plant vertically all around the circumference, after which we wrap a second piece of string called B around the top of the

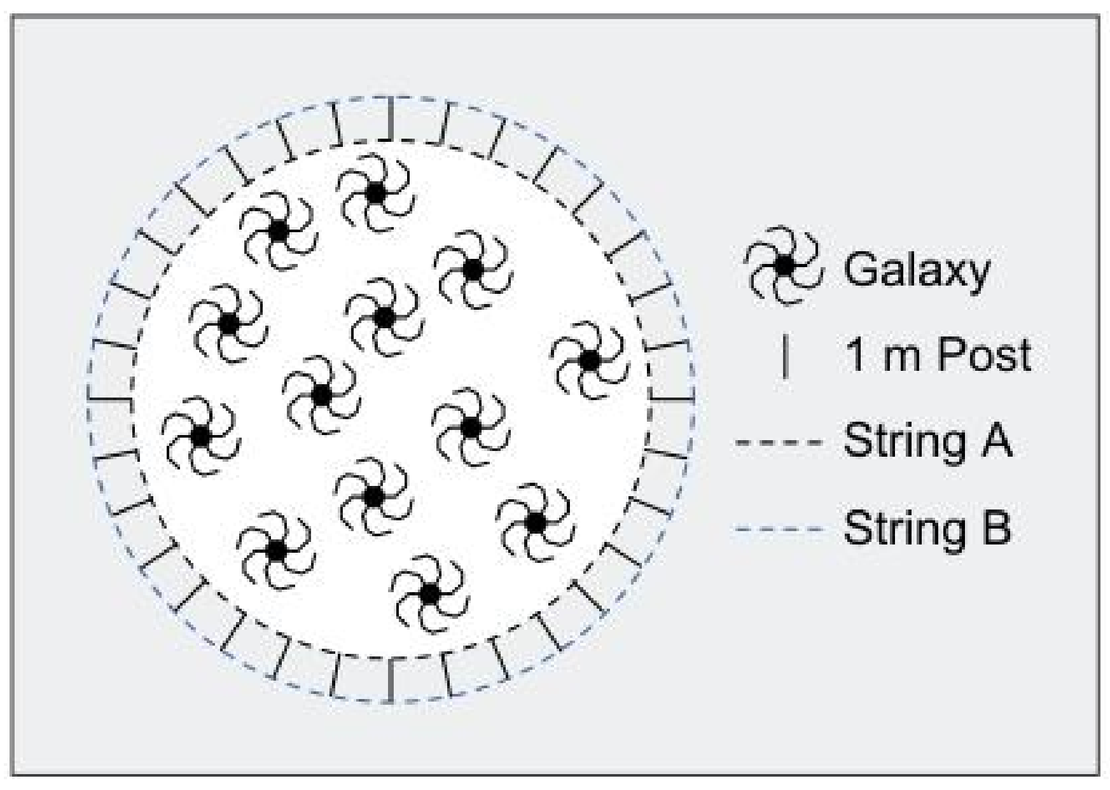


Fig.2. A knotty problem.

posts (Fig.2). (Also assume we are using an infinite number of posts such that string B also follows a truly circular path.)

The diameter of the observable universe (the part we can see) is approximately 93 billion light years (the distance light travels in one year in a vacuum), while the unobservable universe (the part we can't see) stretches beyond that. Just for giggles and grins, let's suppose our 'shell' is 100 billion light years in diameter. Also, as a bonus, I'll save you some time by telling you that one light year equates to approximately 9,500,000,000,000,000 (ie, 9.5×10^{15}) meters. So, how much longer will string B be than string A? (You can find answer at the end of this column.)

Keep on trucking

As you may recall, over the past year we've devoted a large number of *Cool Beans* columns to performing experiments with my 12×12 ping-pong ball array, where each ball is equipped with a tricolour LED in the form of a WS2812 (these devices are also commonly known as 'NeoPixels'). We think of this bodacious beauty as comprising 12 columns (the X-axis) and 12 rows (the Y-axis), both numbered from 0 to 11, with pixel [X,Y] = [0,0] located in the bottom left-hand corner as we face the array.

As an aside, we introduced the concepts of additive, subtractive, primary, secondary and tertiary colours in an earlier column (*PE*, September 2020). For the purposes of these experiments, in addition to black (all off) and white (all on), we are going to restrict our colour palette to three primary colours (red, green, blue) and their corresponding secondary colours (yellow, cyan, magenta). Also, since we will always be driving our LEDs full on in these trials, we won't need to worry about applying a gamma correction fiddle factor (*PE*, January 2021).

So, how can we replicate the aforementioned 'Keep on trucking' scenario with our array? Well, purely for the sake of argument, let's assume that the centre of our ping-pong universe is located at pixel [6,5]. What we are going to do is randomly select a colour from our six primary-secondary palette and light up the pixel at the centre of the universe. This is going to be our spaceship.

Next, we are going to pick a random direction out of eight possibilities – N, S, E, W, NE, NW, SE, and SW – and we are going to make our spaceship move in that direction until it reaches the edge of the universe (one of the sides of our array). At this point, we will extinguish the spaceship pixel and simply pretend it's heading out into the great beyond (Fig.3a). Otherwise, if we were to allow our program to attempt to write to pixels outside of our array, it would end up tramping roughshod through our processor's memory map leaving havoc in its wake.

Once our spaceship has exited the universe, we will pause for a short time, and then repeat the process, each time selecting a new random colour and a new random direction.

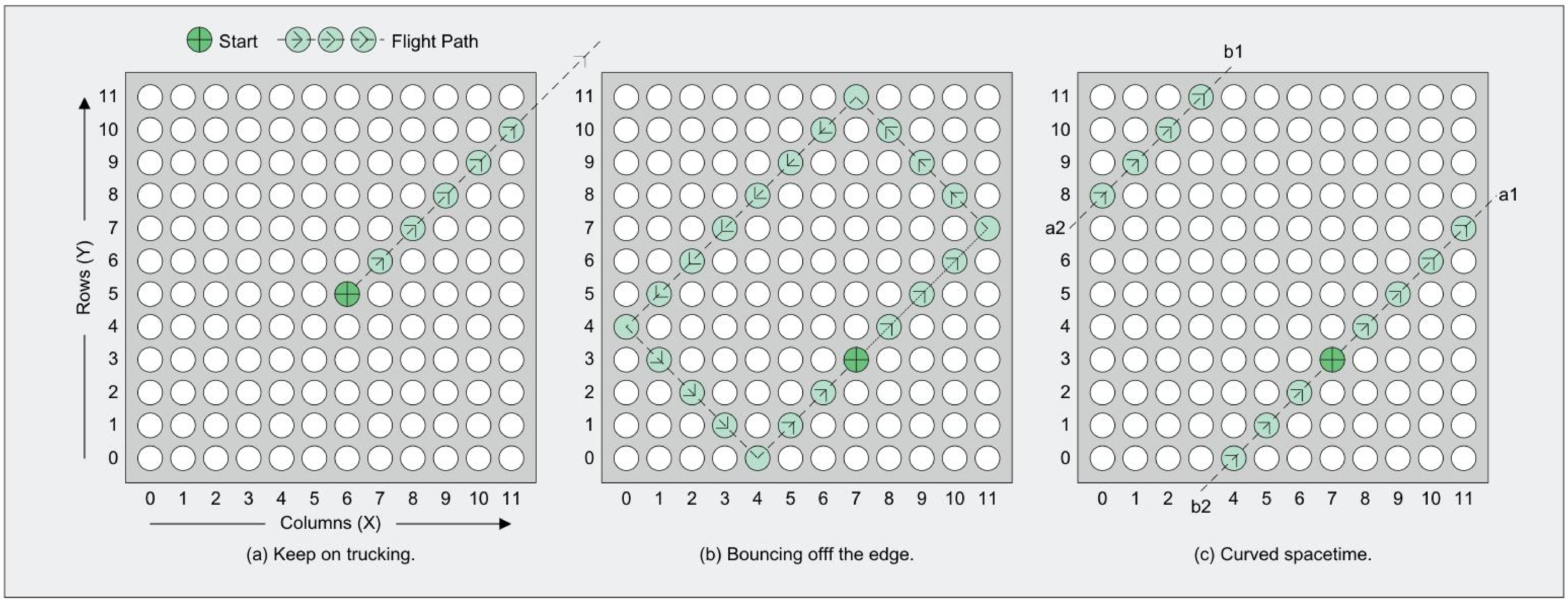
The full sketch (program) for our keep-on-trucking scenario is presented in file **CB-Apr21-01.txt** (it and any other files associated with this article, are available on the April 2021 page of the *PE* website **https://bit.ly/3oouhbl**). We won't go through the entire sketch here, but there are a few things worth noting, such as the fact that we define a new type in the form of a structure we call `ShipDataDefinition`, where 'Ship' refers to our imaginary spaceship (we introduced the concepts of `typedef` (type definitions), `enum` (enumerated types), and `struct` (structures) in *Tips and Tricks*, *PE*, December 2020).

```
typedef struct ShipDataDefinition
{
   int shade;
   int x;
   int y;
   int deltaX;
   int deltaY;
};
```

On the off chance you were wondering, the reason we use the name `shade` rather than `color` is that the latter is already defined and used for some other purpose in the Arduino IDE. Next, we declare a variable called `ShipData` that's of type `ShipDataDefinition`. As part of this declaration, we assign default values to the members of the structure.

```
ShipDataDefinition ShipData =
{
   .shade = COLOR_BLACK,
   .x = 6, .y = 5,
   .deltaX = 0, .deltaY = 0
};
```

Why did we set shade to `COLOR_BLACK`? Well, when we come to generate the colour for a new spaceship, we are going to keep on generating random values until the new colour is different to the old one, so initialising the old colour to be black



(a) Keep on trucking.

(b) Bouncing offf the edge.

(c) Curved spacetime.

Fig.3. Travelling in a ping-pong universe.

as part of the variable declaration means that any colour we generate for our very first ship will be acceptable.

As we discussed earlier, we are assuming that the centre of our ping-pong universe is located at pixel [6,5], which explains the `x = 6` and `y = 5` assignments above. We will be assigning new values to `deltaX` and `deltaY` later. The reason we set them to `0` as part of the declaration was for completeness and to remind ourselves that they are there. The rest of the program is reasonably self-explanatory; the only other thing of note is when we generate a random direction for our spaceship:

```
do
{
   tmpX = random(-1,2);
   tmpY = random(-1,2);
}  while( (tmpX == 0) && (tmpY == 0) );

ShipData.deltaX = tmpX;
ShipData.deltaY = tmpY;
```

As discussed in this month's *Tips and Tricks*, the Arduino's `random()` function returns a pseudo-random integer between the set specified by the minimum and maximum values (which are defined as –1 and +2, respectively, in this example). The trick is that the minimum value is 'inclusive' (ie, included in the set) while the maximum value is 'exclusive' (ie, excluded from the set), which means that `random(-1,2)` will return a random value of –1, 0, or +1.

What we are going to do is loop around repeatedly, adding these `deltaX` and `deltaY` values to our main `x` and `y` values, thereby guiding our spaceship on its designated trajectory. We can accept any combination of `deltaX = –1` or `0` or `+1` and `deltaY = –1` or `0` or `+1`, except the case when they are both `0`, because in that case the ship wouldn't be going anywhere. This explains the test associated with the `while()`, which means we will keep on generating new random values until we have any combination other than both `tmpX` and `tmpY` being `0`.

As an aside, there's nothing in our current code to prevent the direction of the new spaceship being the same as that of the previous ship. We could easily extend the test associated with the `while()` to check for this if we wished. Why don't you jot down your ideas for such a test now? – I'll reveal one possibility at the end of this column.

In this scenario, our ship will keep on moving until it reaches one of the sides of the array, at which point we will return the pixel to black and pretend the ship is still trucking on its merry way outside of the array.

Bouncing off the edge

Our next scenario is when the ship bounces of the edge of the universe. The way the bounce works depends on the direction the ship is travelling when it hits the side of the array. For example, if the ship starts off travelling to the right (East), then when it hits the side it will bounce back to the left (West), and it will continue to ricochet back and forth between these two sides. Similarly, if the ship starts off travelling up (North), then when it hits the edge it will bounce back down (South), and it will continue to ricochet between *these* two sides. A third alternative is when the ship starts off travelling at a 45-degree angle, say North-East, in which case its path will be an inclined rectangle (Fig.3b).

Looking ahead to our curved spacetime future, what we are going to do in this current scenario is create six spaceships, each with a different colour. The first will start off heading North, the second South, the third East, the fourth West, the fifth North-East, and the sixth South-West. In this case (noting that `NUM_SHIPS` is defined as being 6), we can declare and initialise our six spaceships as an array as follows:

```
ShipDataDefinition ShipData[NUM_SHIPS] =
{
   // Assignments go here
};
```

If you look at the full program (file **CB-Apr21-02.txt**), you'll observe that the `deltaX` and `deltaY` fields associated with ships #1 through #6 are assigned appropriate –1, 0, +1 values required to achieve the desired directions:

```
#1 deltaX =  1, deltaY =  0
#2 deltaX = -1, deltaY =  0
#3 deltaX =  0, deltaY =  1
#4 deltaX =  0, deltaY = -1
#5 deltaX =  1, deltaY =  1
#6 deltaX = -1, deltaY = -1
```

As you'll see, the work we've done in defining things like our `ShipData[]` array really starts to pay off here because the body of our program that makes the six ships fly around our ping-pong ball array is surprisingly compact and easy to understand.

One thing you might observe is that each time round the loop, before we calculate and display their new positions, we first set the colour of all the current spaceship locations to black. The reason for this is that our program isn't very sophisticated, and the ships are unaware of each other's positions. If we weren't careful, we might display the new location of ship A on top of the old position of ship B, and then set the old position of ship B to be black. Setting all of the old locations to black first addresses this problem.

If we wished to get really clever, our program could keep track of the positions of all of the ships and, if two or more found themselves in the same location, we could set the colour of that pixel to be a merged value of the various ship colours, but things are happening so fast that this really isn't worth the effort.

The key thing to note in this scenario is that, when one of our spaceships hits a side, we will negate the appropriate delta value. For example, if a ship is heading East (`deltaX = 1`, `deltaY = 0`), then when it hits the side, we will change `deltaX` to be `-1`, which will cause that ship to start heading West. Similarly, if a ship is heading South (`deltaX = 0`, `deltaY = -1`), then when it hits the side, we will change `deltaY` to be `+1`, which will cause that ship to start heading North.

Curved spacetime

Finally, we come to consider our curved spacetime scenario. This can be a little difficult to wrap one's brain around at first, so let's take things step-by-step. Suppose our spaceship commences heading East. In this case, we can imagine our universe (in the form of our ping-pong array) being curled into a vertical cylinder such that the right-hand side is joined to the left-hand side. What this means is that, when our ship reaches the right-hand side, it will disappear and reappear – still moving East – on the same row at the left-hand side.

By comparison, if our ship commences heading South, we can imagine our universe being curled into a horizontal

Want to build your own amazing ping-pong ball array? All the details are in previous *Cool Beans* columns, starting in March 2020.

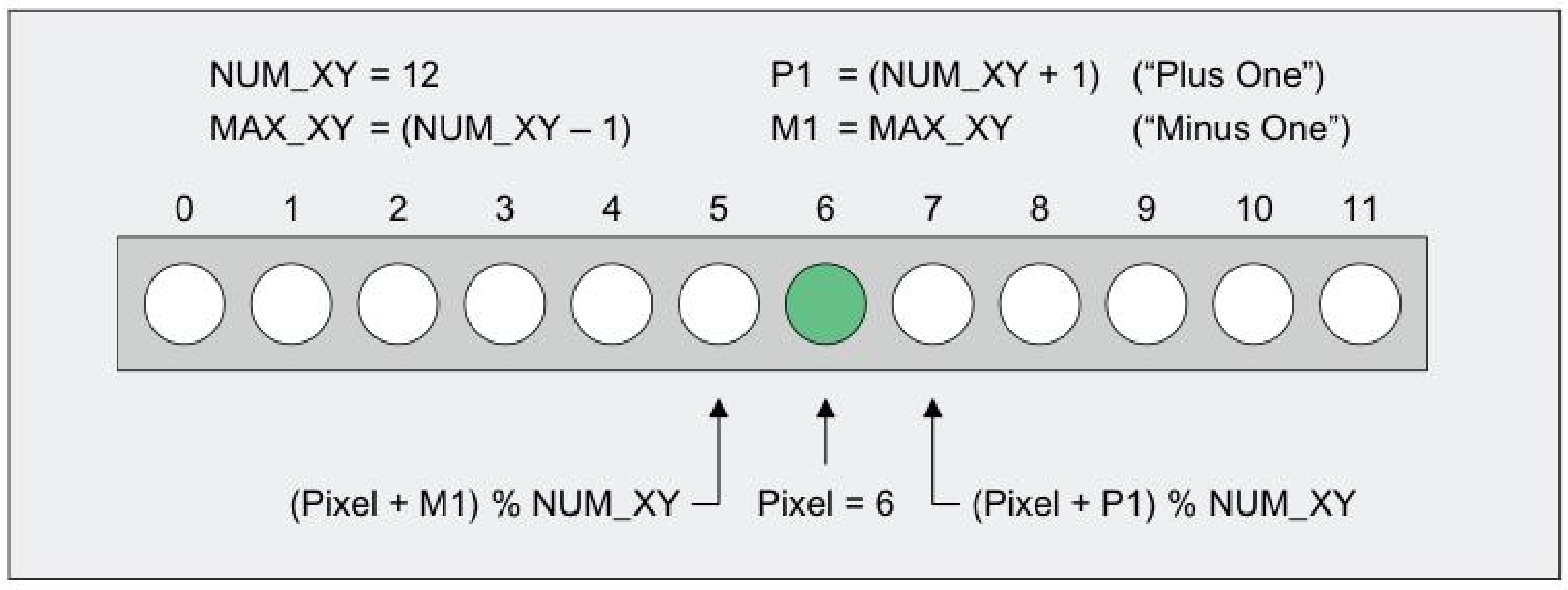


Fig.4. Single versus multiple drips.

cylinder such that the upper side is joined to the lower side. In this case, when our ship reaches the lower side, it will disappear and reappear – still moving South – on the same column at the upper side.

When you feel comfortable with this, consider what will happen if our ship commences at location [7,3] heading in a North-East direction (Fig.3c). When it reaches the right-hand edge at location a1, it will reappear one column to the 'right' (ie, on the left-hand edge) and one row higher at location a2, still travelling in a North-East direction. One way to think about this is if, just as the ship reaches the right-hand edge at [11,7], we were to split the array into two vertical halves, each six pixels wide. We then move the left-hand half to the right of the right-hand half, if you see what I mean.

Similarly, when the ship reaches the upper edge at location b1, it will reappear one row 'higher' (ie, on the lower edge) and one column to the right at location b2, still travelling in a North-East direction. One way to think about this is if, just as the ship reaches the upper edge at [3,11], we were to split the array into two horizontal halves each six pixels tall, and then move the upper half to be underneath the lower half.

In order to ensure everything works as we desire, let's once again create six spaceships, each with a different colour, commencing with headings of North, South, East, West, North-East, and South-West, respectively.

The first point to note is that we can't use delta values of –1 and +1 to move left or right, or up or down, respectively, because doing so would cause chaos and confusion when a ship arrived at one of the edges. The solution is to use variations of the modulo operations we discussed in my previous column (*PE*, March 2021). Purely for the purposes of providing an example, consider a single row of 12 ping-pong balls numbered left-to-right from 0 to 11. Now assume we are looking at pixel 6 (Fig.4).

As we know, the modulo operator returns the integer remainder from the division of two integer numbers. The number of pixels we have in a row (or column) is 12 (`NUM_XY`) numbered from 0 (`MIN_XY`) to 11 (`MAX_XY`). As we see in the figure, we define `P1` ('Plus One') to be `(NUM_XY + 1) = 13`, while `M1` ('Minus One') is defined as being `MAX_XY = 11`.

So, if we are looking at `Pixel = 6`, the pixel to the right will be `(Pixel + P1) % NUM_XY`, which equates to (6 + 13) % 12 = 19 % 12 = 7. Similarly, the pixel to the left will be `(Pixel + M1) % NUM_XY`, which equates to (6 + 11) % 12 = 17 % 12 = 5. Try performing the same calculations with starting pixel numbers of 0 and 11, which represent our boundary conditions, and you'll see that everything works out the way we wish. All I can say is 'Tra-la!' (and I mean that most sincerely).

Now, this is where things become very interesting because we can quickly and easily tweak our previous code to address this new scenario. If you look at the full sketch (file **CB-Apr21-03.txt**), you will see that we start by modifying the `deltaX` and `deltaY` values in our `ShipData[]` declaration as follows:

```
#1 deltaX = P1, deltaY =  0
#2 deltaX = M1, deltaY =  0
#3 deltaX =  0, deltaY = P1
#4 deltaX =  0, deltaY = M1
#5 deltaX = P1, deltaY = P1
#6 deltaX = M1, deltaY = M1
```

The really cool stuff becomes obvious when we come to moving our ships. As you'll see, we no longer have to perform tests to detect any boundary conditions because our spacetime is curved and the ships don't even see the edges of the universe.

If you are interested, I just created a video showing everything we've discussed here in glorious technicolor action – just visit: **https://bit.ly/3dLdHAB**.

Conway's Game of Life

I know, I know… At the end of my previous column, I said that we would implement *Conway's Game of Life* (*GOL*) in this column 'or my name's not Max the Magnificent!' Well, I was right, because my name isn't Max the Magnificent – that's just what people call me (in my dreams).

The thing is, we are going to run into the same 'Edge of the Universe' problems with the *GOL* and – now that we know how to address those issues – we are quivering in anticipation ready to rock and roll. Until next time, have a good one!

The solution to our `while()` conundrum

In our keep-on-trucking scenario, the test associated with our `while()` statement was `((tmpX == 0) && (tmpY == 0))`, which says we will keep on generating new random values for `tmpX` and `tmpY` until we have any combination other than both of them being `0`.

Now, suppose we wish to enhance this test such that we also keep on generating new random values for `tmpX` and `tmpY` until at least one of them differs from their previous values, which are currently stored in `deltaX` and `deltaY`, respectively. We could achieve this part of the test using: `((tmpX == deltaX) && (tmpY == deltaY))`

The way to think about this is that we wish to keep on generating new random values so long as either of these sub-tests returns true; that is, if the first test returns true OR the second test returns true. One way to achieve this would be to use: `while( ((tmpX == 0) && (tmpY == 0)) || ((tmpX == deltaX) && (tmpY == deltaY)) );`

The solution to our knotty problem

I have a bit of a confession to make. The reason I was waffling on about the diameters of the observable and unobservable universes and the number of meters in a light year was to throw you off the scent. In reality, the difference in the lengths of strings A and B will be the same, irrespective of the diameter of the universe.

How can this be? Well, the circumference of a circle is given by $2\pi r$. Let's say that the radius of our shell is (x) meters, which means the length of string A will be $2\pi x$ meters. Since we are using 1m posts, this means, the radius of the circle defined by string B will be (x + 1) metres. In turn, this means the length of string B will be $2\pi(x + 1)$ metres, which equals $2\pi x + 2\pi$. Since the length of string A was $2\pi x$ metres, this means that the difference in length of string B will be $2\pi x + 2\pi - 2\pi x = 2\pi$ metres (ie, approximately 6.28m) longer. This is true for a 10m-radius ball, the Earth or the entire observable universe!

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

Max's Cool Beans cunning coding tips and tricks

Every now and then, we wish to add some amount of randomness into our programs. For example, we might want to create an electronic version of a dice. In this case, we need to use some sort of random-number generator (RNG). In fact, generating a truly random sequence of numbers is very difficult. An easier alternative is a *pseudo-random* number generator (PRNG), also known as a 'deterministic random bit generator' (DRBG), which is an algorithm for generating a sequence of numbers whose properties approximate the properties of sequences of truly random numbers.

Aah, the Arduino

And so we turn our attention to the Arduino and its `random()` function, which allows us to generate pseudo-random integers between a minimum and maximum range that we specify. Generally speaking, the creators of the Arduino tried to make things as simple as possible for beginners. However, for reasons that defy explanation, they decided to make the minimum value 'inclusive' while the 'maximum' value is exclusive'. Consider the following statement, for example: `int tmpRnd = random(5, 10);`

In this case, `tmpRnd` will end up containing a pseudo-random value out of the set 5, 6, 7, 8, and 9, but not 10, because 5 (the minimum value) is included in the set while 10 (the maximum value) is excluded. If only one value is specified, then this is assumed to be the maximum value and the minimum is automatically set to zero, so `random(10)` produces identical results to `random(0,10)`.

One nice thing about the Arduino's `random()` function is that it allows us to generate negative numbers, so `random(-10,10)` will return a random value between –10 and +9.

What a memory!

As we will see in a moment, PRNGs need to be provided with an initial 'seed' value before they perform their magic. Unless we overwrite it, the Arduino will use some default seed value (I have no idea what this value is). Furthermore, the Arduino's PRNG would be classed as non-volatile, because – by default – it will 'remember' and employ the same seed value each time it's powered up. Consider the following snippet of code, which generates groups of five pseudo-random numbers between 0 and 99, for example:

```
void loop()
{
   for (int iRnd = 0; iRnd < 5; iRnd++)
   {
      int tmpRnd = random(0, 100);
      Serial.println(tmpRnd);
   }
}
```

When I run this code on my Arduino Uno, I receive the following sequence of numbers (I've broken them up into groups of five for clarity): 7, 49, 73, 58, 30; 72, 44, 78, 23, 9... Every time I re-run the program; I'm presented with exactly the same sequence.

Planting a seed

So, what happens if we change the seed value? Well, let's assume we keep the same code in our `loop()` function as before, but we add the statement `randomSeed(10)` to our `setup()` function. Note that the 'random seed' moniker is not intended to imply that this function generates a random seed value; rather that it will modify the seed value of the Arduino's PRNG to be the specified positive integer, which is 10 in this example (a word to the wise; don't use a seed value of 0; nuff said).

Now, when I run this modified code on my Arduino Uno, I receive the following sequence of numbers (which is different to what we saw before): 70, 43, 1, 92, 65; 26, 40, 98, 48, 67... And, once again, every time I re-run the program; I'm presented with exactly the same sequence.

Just for giggles and grins, what do you think would happen if we remove the `randomSeed(10)` statement from the `setup()` function and insert it into the `loop()` function as follows:

```
void loop()
{
   randomSeed(10);
   for (int iRnd = 0; iRnd < 5; iRnd++)
   {
      int tmpRnd = random(0, 100);
      Serial.println(tmpRnd);
   }
}
```

Basically, we are resetting our PRNG to the same starting point before we generate each batch of five random numbers. This results in our generating the same group of five numbers over and over again: 70, 43, 1, 92, 65; 70, 43, 1, 92, 65...

Even more random

It may be that we are happy with the fact that the same pseudo-random sequence appears every time we run our program. Scientists and engineers, for example, often require 'repeatability' in their experiments. On the other hand, if you are creating something like a slot machine destined for the hallowed halls of Las Vegas, having it perform the same sequence each time it's powered up would not be considered to be a desirable feature. And, of course, in some cases, like the programs in this month's *Cool Beans*, we really don't care either way.

So, how could we set about ensuring that our program employs a different seed value each time it's run? One way would be to require the user to press a pushbutton switch, and to use the elapsed time between power being applied to the system and the user activating the switch as the seed value for the PRNG. Another alternative would be to use the fact that any unconnected ('floating') analogue inputs on the Arduino tend to wander around in value. Suppose we return to our original snippet of code but we add the following statement into our `setup()` function:

```
randomSeed( analogRead(A0) );
```

When we perform the `analogRead()` on input `A0`, we are going to receive a somewhat random value, and this is the value we use to seed the PRNG. In my case, the first time I ran this program, I received the following sequence: 99, 31, 18, 45, 80; 38, 56, 72, 37, 62... The next time I ran the program, I received a completely different sequence: 41, 78, 21, 52, 19; 23, 73, 52, 87, 34...

To be honest, we've only scratched the surface of the topic of randomness here, but at least we now know enough to be dangerous, as explained here: **http://bit.ly/pe-apr21-999999**

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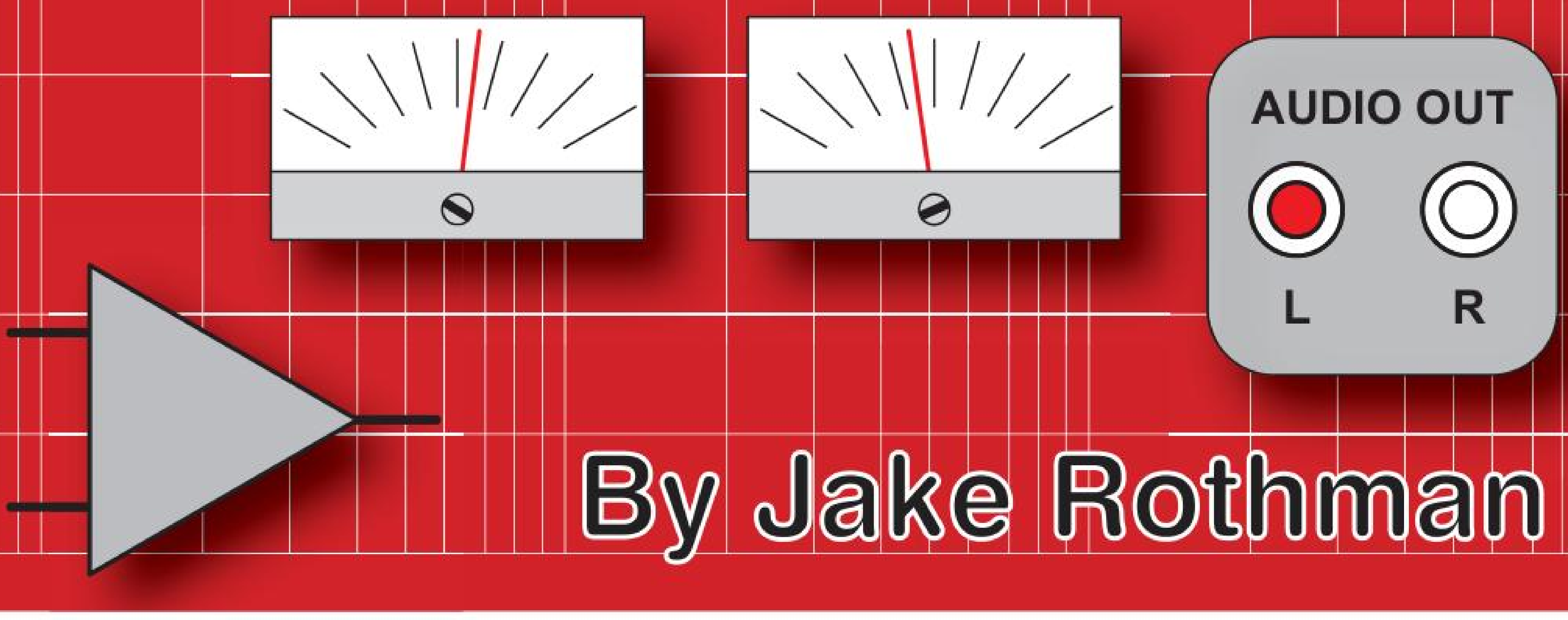

By Jake Rothman

Making a Transistor Radio – Part 2

Last month, we introduced the *Ladybird Transistor Radio* and got as far as building a simple crystal set. This month, we go active and build the full transistor version, plus we'll suggest some simple upgrades to improve performance but still retain the spirit of the germanium-based electronics.

The active radio

The next stage is a major upgrade; we are going to add audio amplification to the crystal set using a transistor and a battery (Fig.14). All this does is make the crystal set a bit louder. It was just sufficient for me to hear it. I was disappointed to find the original circuits suggested in the Ladybird book did not work properly, since the biasing was all out. The main problem was that the diode had a DC voltage on it. This was fixed by adding a coupling capacitor and re-jigging the bias values to get the output to sit at half-rail, as shown in Fig.15. This could be made insensitive to transistor H_{fe} variations by including a 1kΩ emitter resistor. This should be bypassed with a capacitor of around 22µF, as shown in Fig.16. Replacing the 2.7kΩ resistor and crystal earpiece with the telephone earpiece sounded much better (see circuit in Fig.17). The crystal types do have a rather 'tinny' response.

Reflex radio

Given the simple design we are working with, there was only one simple way to get a usable signal and that was to build a regenerative or reflex radio circuit, as shown in Fig.18. Although this design has both gain and selectivity, it only needs one transistor, which is effectively used twice; combining both an RF amplifier and audio amplifier stage together. The audio load is the collector resistor R2, while the RF load is the choke L2. In the old days, a transistor was much pricier than an inductor. Today the situation is reversed, and at least two transistors would be used, but with a doubling of power consumption.

Positive feedback is also applied, 'regeneration' or 'reaction' as it is know in wireless parlance. This is used to 'peak' the tuned circuit. As with all positive feedback, there is a real risk that too much can result in oscillation, causing the radio to act like a transmitter!

The two-diode network is for detecting the audio and is basically a voltage doubler circuit. The output of this is fed back into the transistors input again. Germanium diodes work best here, since silicon types can cause instability. The original Ladybird reflex construction is shown in Fig.19.

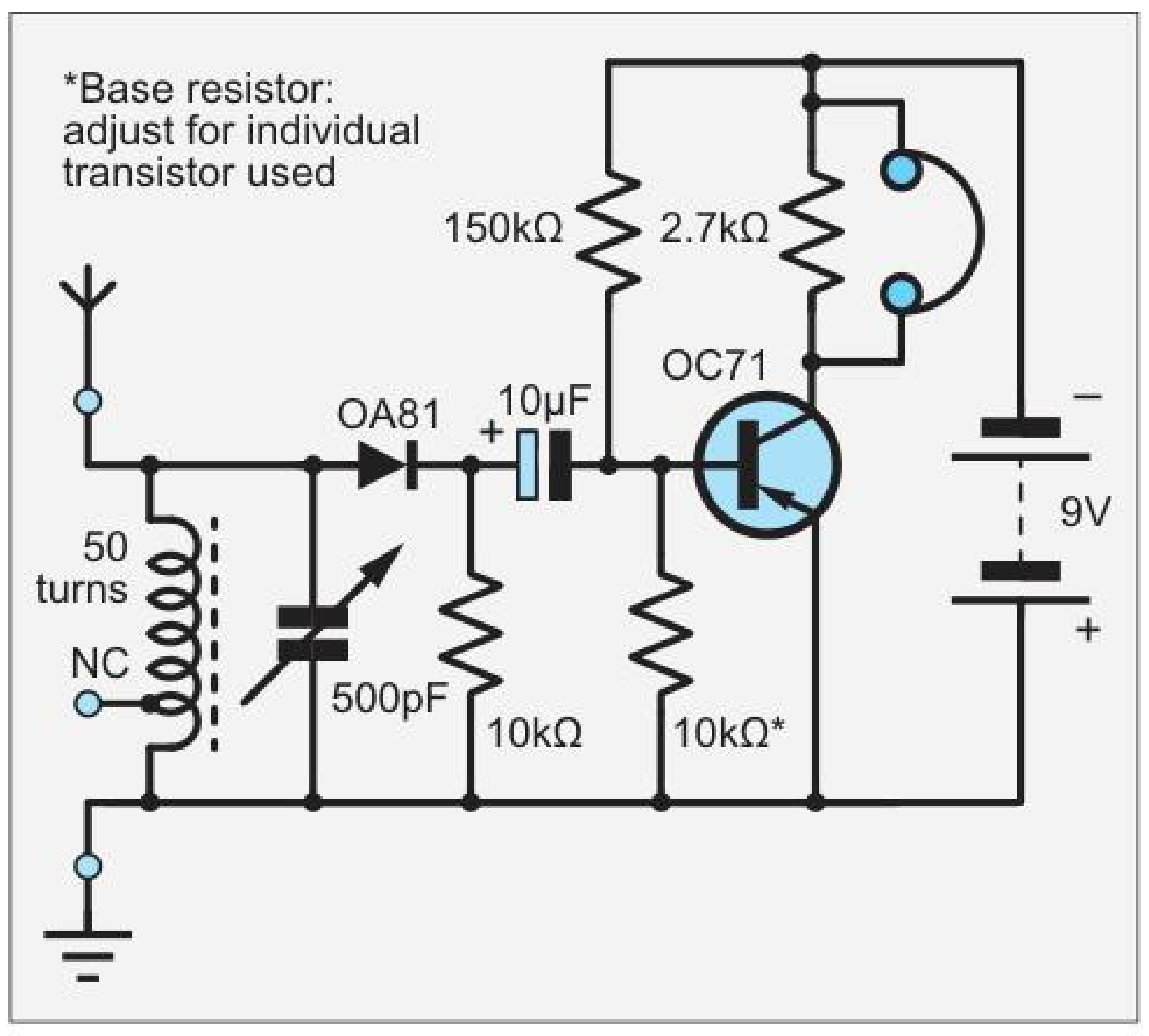

Fig.15. Adding a coupling capacitor and adjusting biasing on Fig.14.

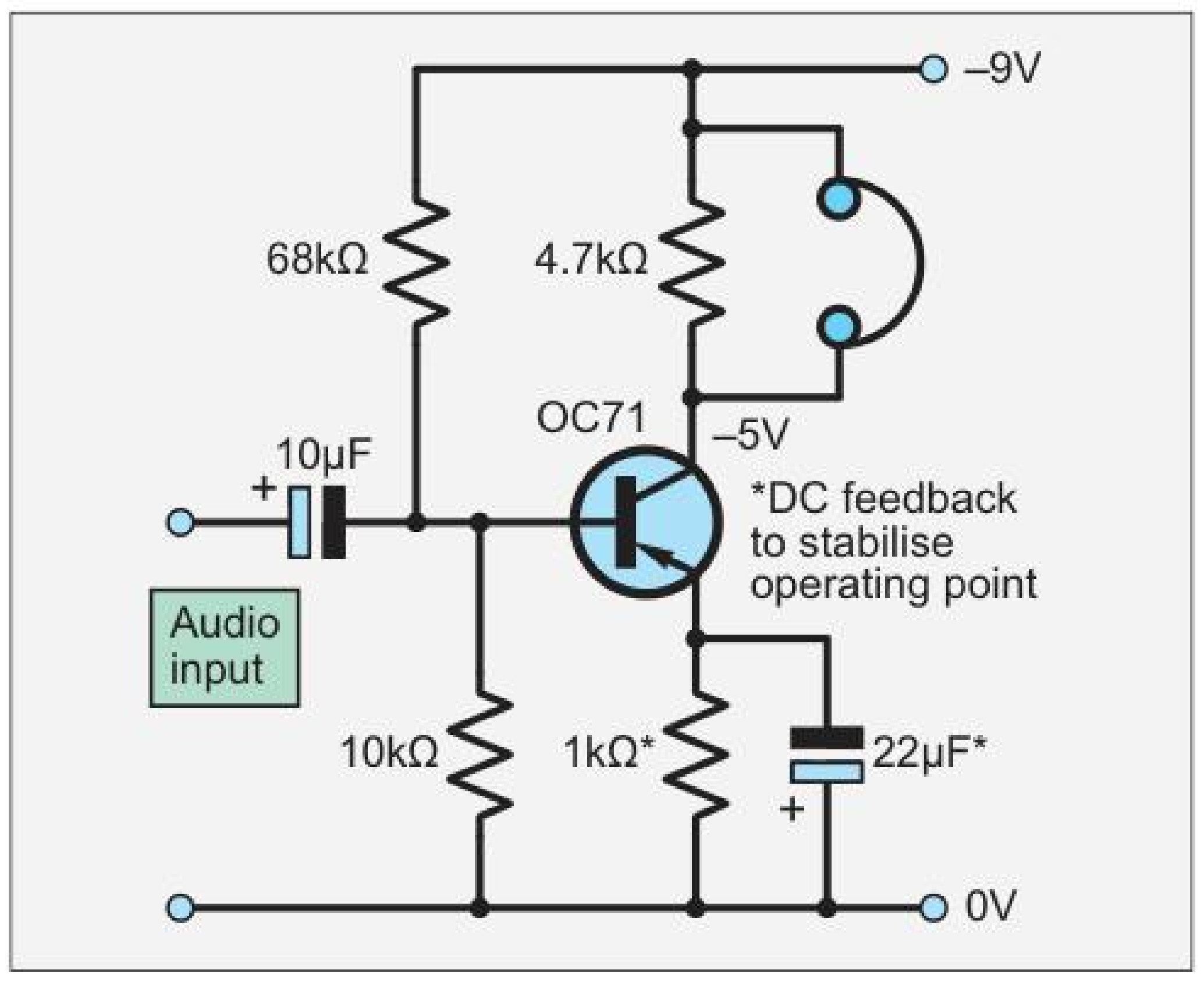

Fig.16. Crystal set with improved single-stage amplifier. Adding an emitter resistor and a bypass capacitor to the circuit in Fig.15 gives better transistor variation tolerance.

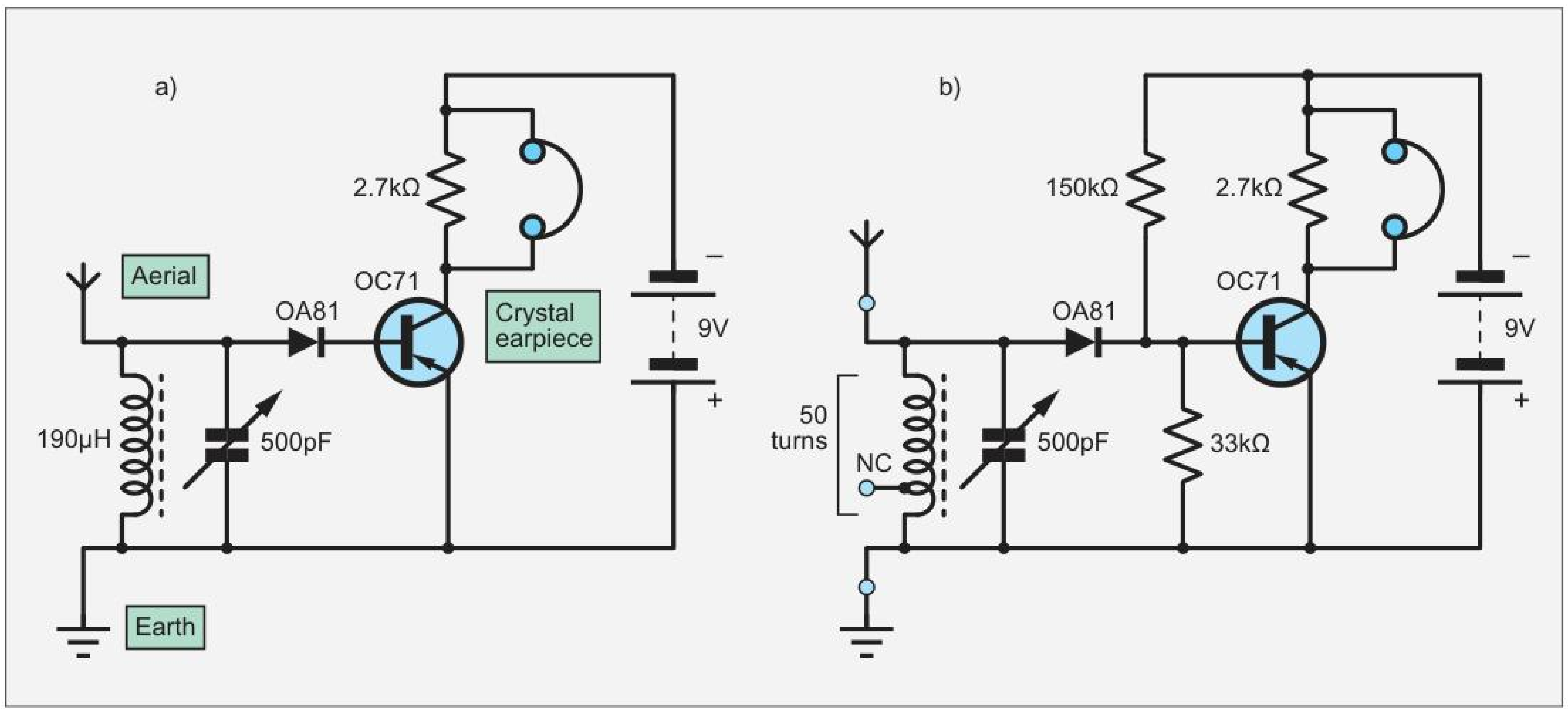

Fig.14. Adding a single-stage amplifier to the crystal set: a) transistor with no bias; b) biased transistor, but the base voltage stops the diode conducting.

Component notes

For a retrospective project like this, the components have to look the part – no anonymous black surface-mount devices here. Sourcing classic glass-cased diodes is a good start.

Screws

Solid brass No.4 or No.6, 3/8-inch (10mm long × 2mm wide) screws with a countersunk head are used. These are normally only available in slotted head. The cups are No.6 (11mm across with 3.5mm hole). I was worried about the lacquer spoiling the contact, but this was

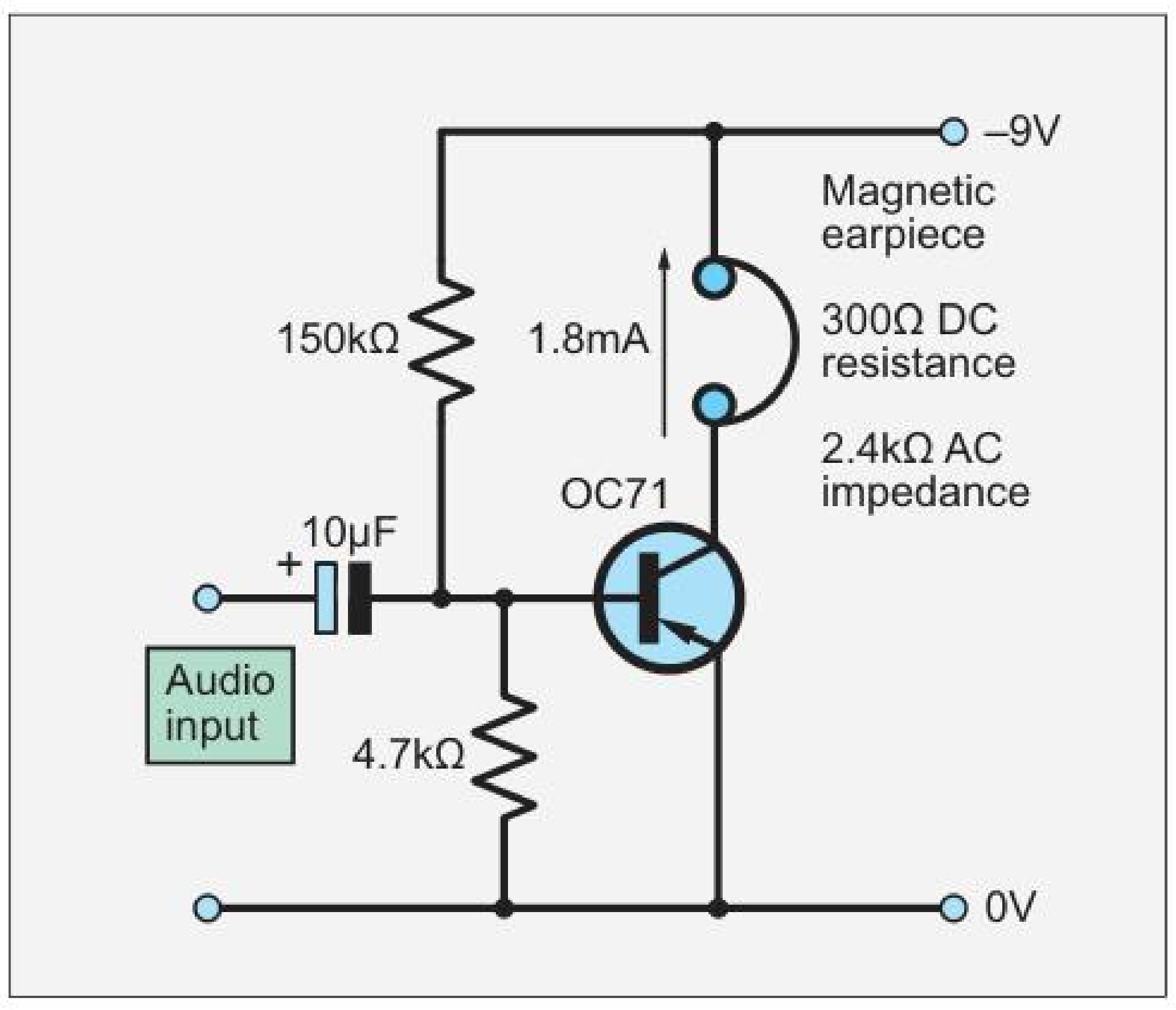
–9V
Magnetic earpiece
300Ω DC resistance
2.4kΩ AC impedance
150kΩ
1.8mA
OC71
10µF
+
Audio input
4.7kΩ
0V

Fig.17. Adding a telephone earpiece; this sounds better than the crystal unit.

not the case. I used No. 5/6 cups with No.4 screws and had no problems. The brass-plated types do work but may oxidise with time. Solid brass cups are available, but expensive.

Transformers

One way of improving the sensitivity of the crystal set is to feed a crystal earpiece via a step-down 20kΩ-to-1kΩ driver transformer, such as the LT44 shown in Fig.20, to increase the load impedance further. The inductance of this resonates with the earpiece's capacitance to further boost output. This transformer also works well with the old balanced-armature telephone receivers illustrated in Fig.21. These have an AC impedance of 2.4kΩ and a DC resistance of 300Ω. Using the transformer in the collector of the transistor amp with the telephone earpiece finally increased output to a usable level.

Output transformer

The output transformer is that hobbyist's favourite, the Eagle LT700. This has an impedance ratio of 1.2kΩ to 3.2Ω. The output of the *Ladybird Radio* is very low, in the order of about 50mW, just over 1V peak to peak into 3Ω. If double output power is needed, an LT726, or the bigger LT730 could be used, which have 500Ω primaries. Their secondaries can drive 3Ω or 8Ω speakers. If you can get one, the Repanco or RS T/T4 is the best, since it is designed to have DC flowing through the core. Overseas readers could use the Xicon 42TU400-RC from Mouser. The standing current will have to be increased to 14mA for these transformers by reducing bias resistor R_{Bias} (Fig.20) to 51kΩ, which will be too much for a PP3 battery. I decided the original LT700 was overall the best for the job and put it back after trying the others. I also tried a Philips 80mm 150Ω high-impedance speaker wired directly, and that worked well.

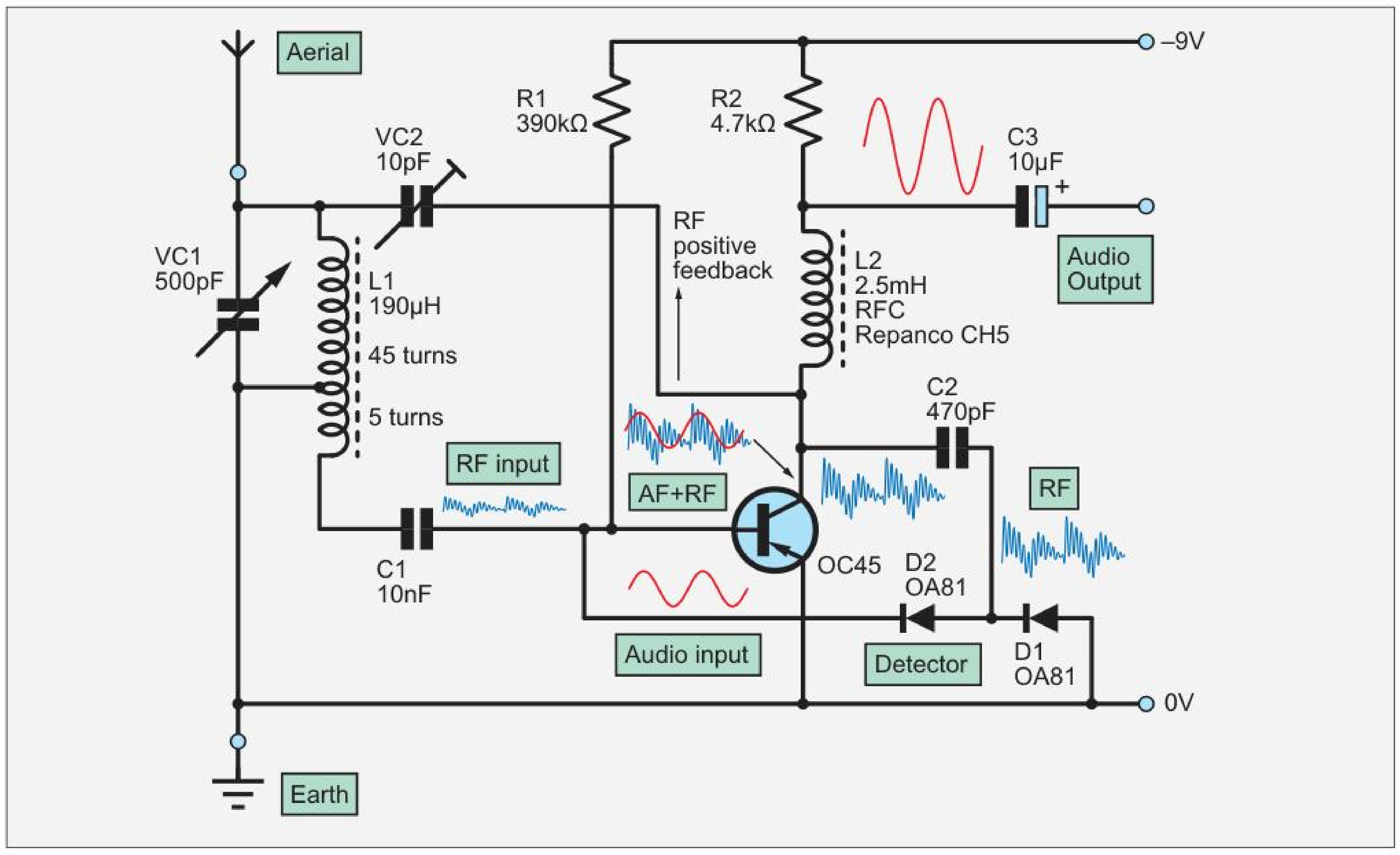
Aerial
–9V
R1
390kΩ
R2
4.7kΩ
VC2
10pF
C3
10µF
+
RF positive feedback
Audio Output
VC1
500pF
L1
190µH
45 turns
5 turns
L2
2.5mH
RFC
Repanco CH5
C2
470pF
RF input
AF+RF
RF
C1
10nF
OC45
D2
OA81
Audio input
Detector
D1
OA81
0V
Earth

Fig.18. Reflex radio circuit – the transistor is used twice, note audio (red) and radio (blue) frequency pathways.

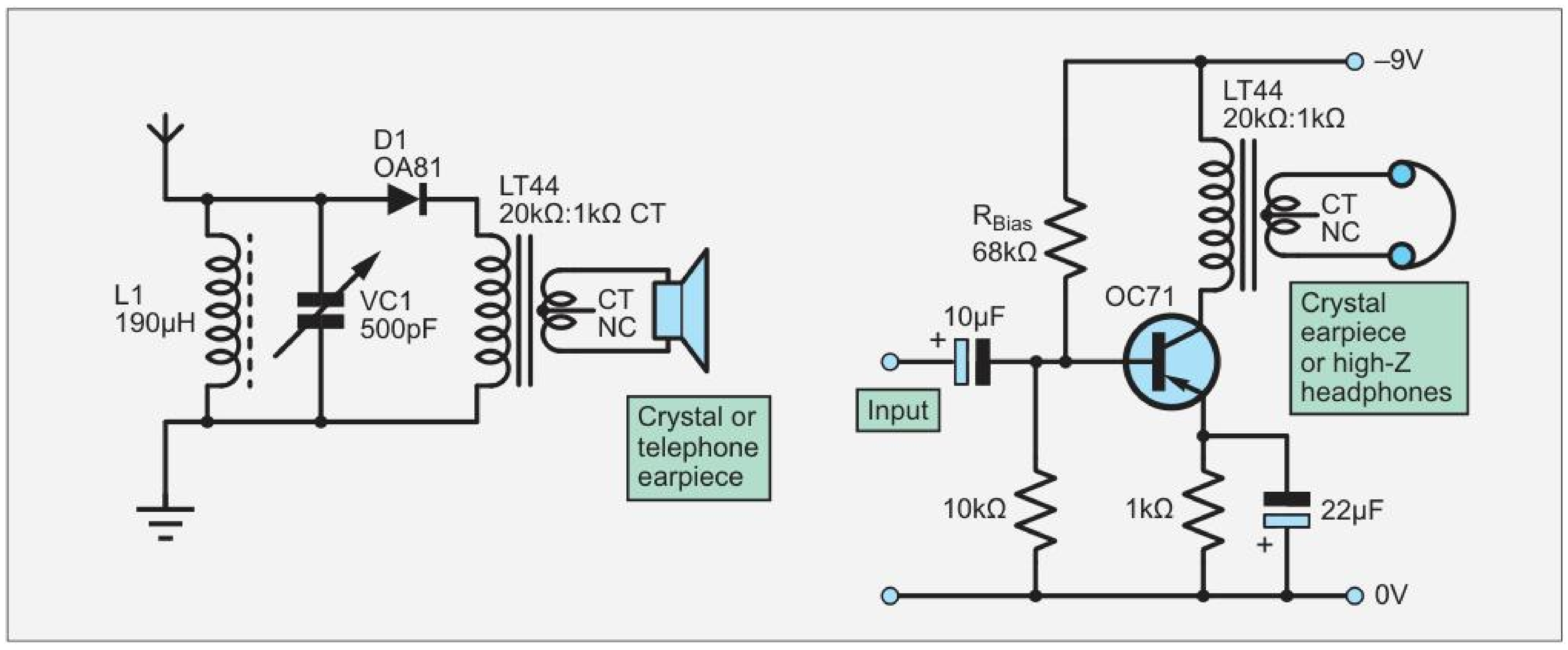
D1
OA81
LT44
20kΩ:1kΩ CT
L1
190µH
VC1
500pF
CT
NC
Crystal or telephone earpiece
–9V
LT44
20kΩ:1kΩ
R_{Bias}
68kΩ
CT
NC
10µF
+
OC71
Crystal earpiece or high-Z headphones
Input
10kΩ
1kΩ
22µF
+
0V

Fig.20. Adding an audio transformer to the crystal set increases output.

Germanium transistors

Watch out for types that are too 'good'. Using non-stabilised bias (as in Fig.23) caused most transistors to turn hard-on. The low-gain OC70 might have been worked better here. I dropped bias resistor

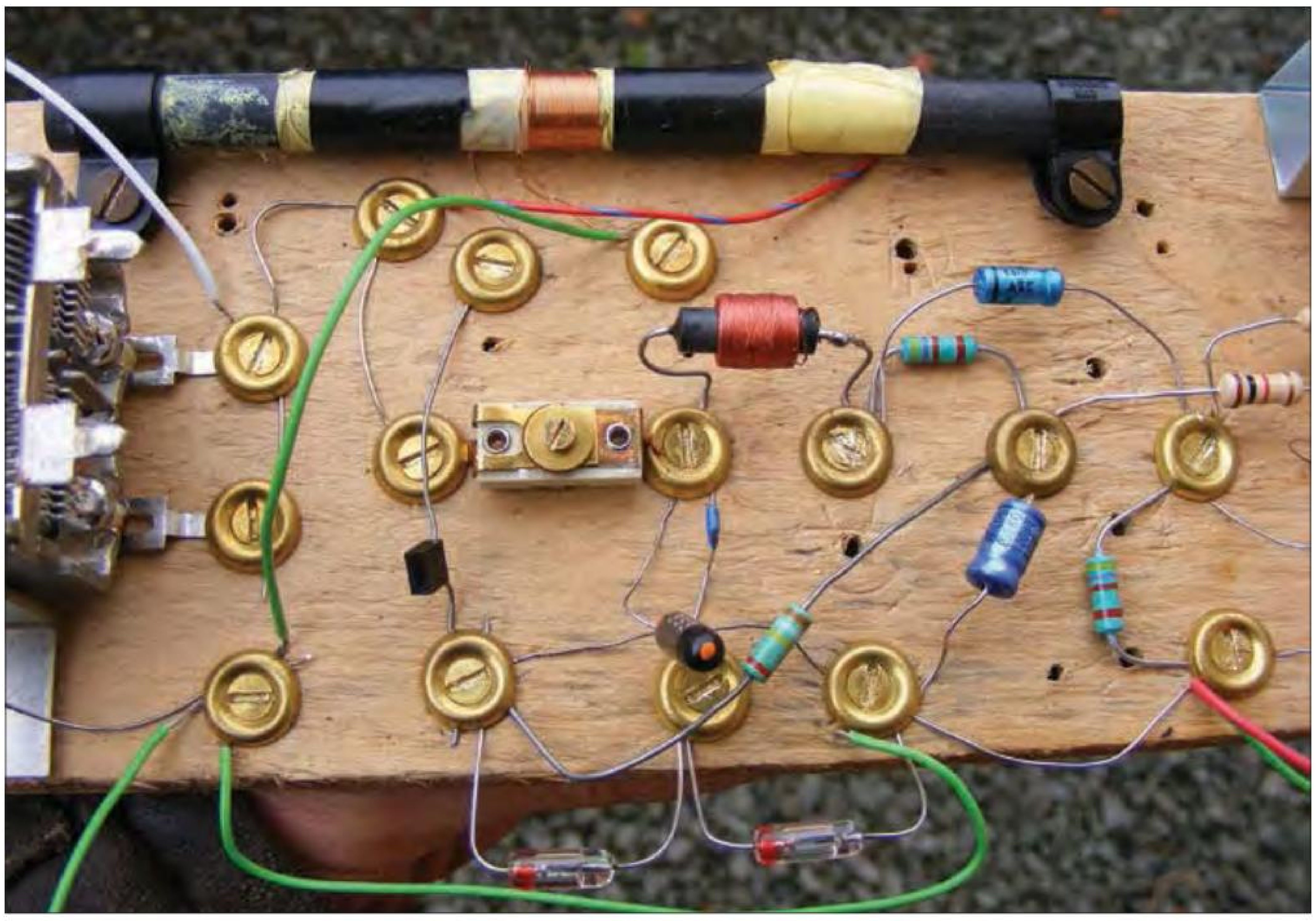

Fig.19. Construction of the reflex circuit.

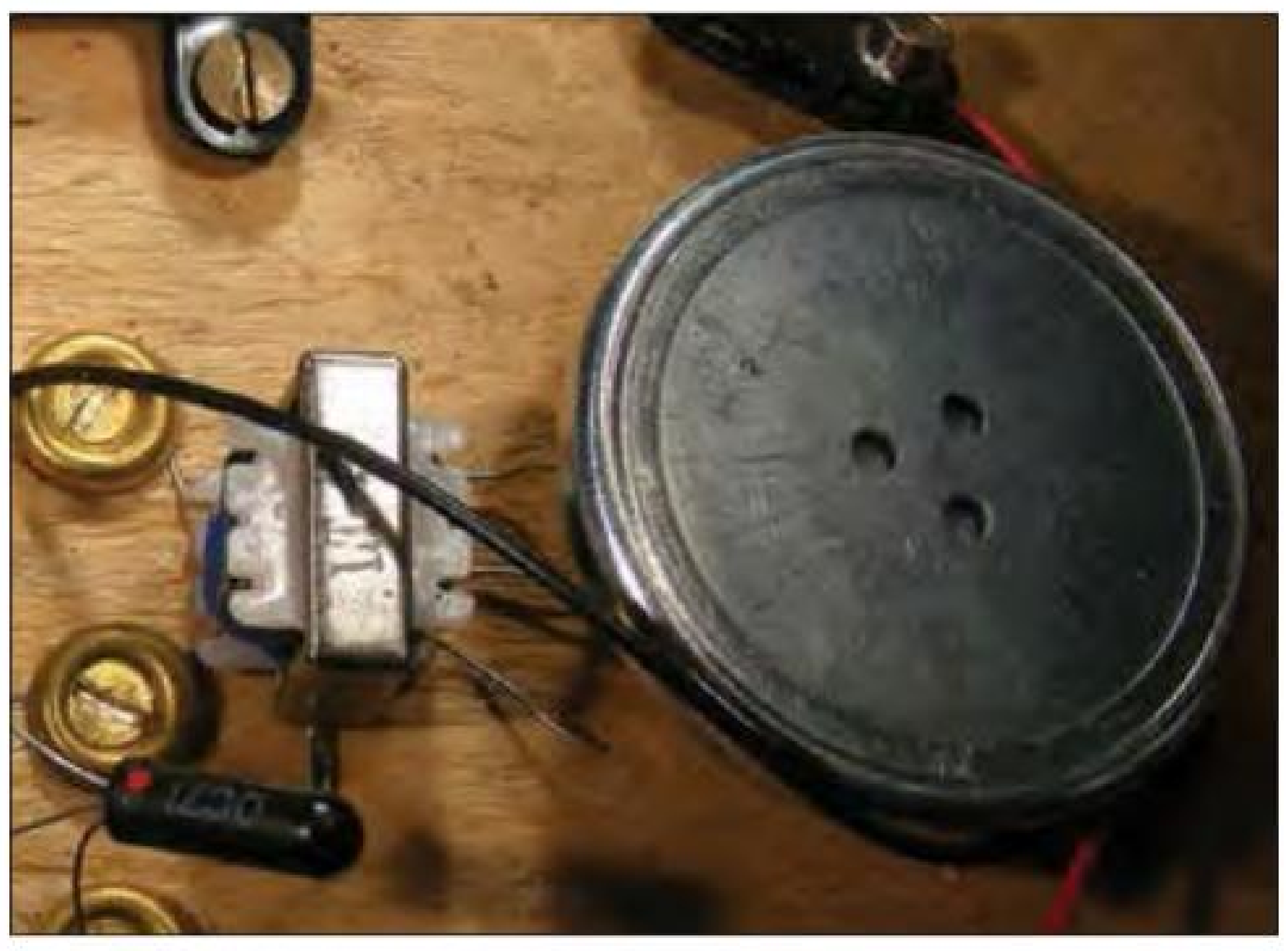

Fig.21. Telephone earpiece – use of an LT44 transformer also improves output.

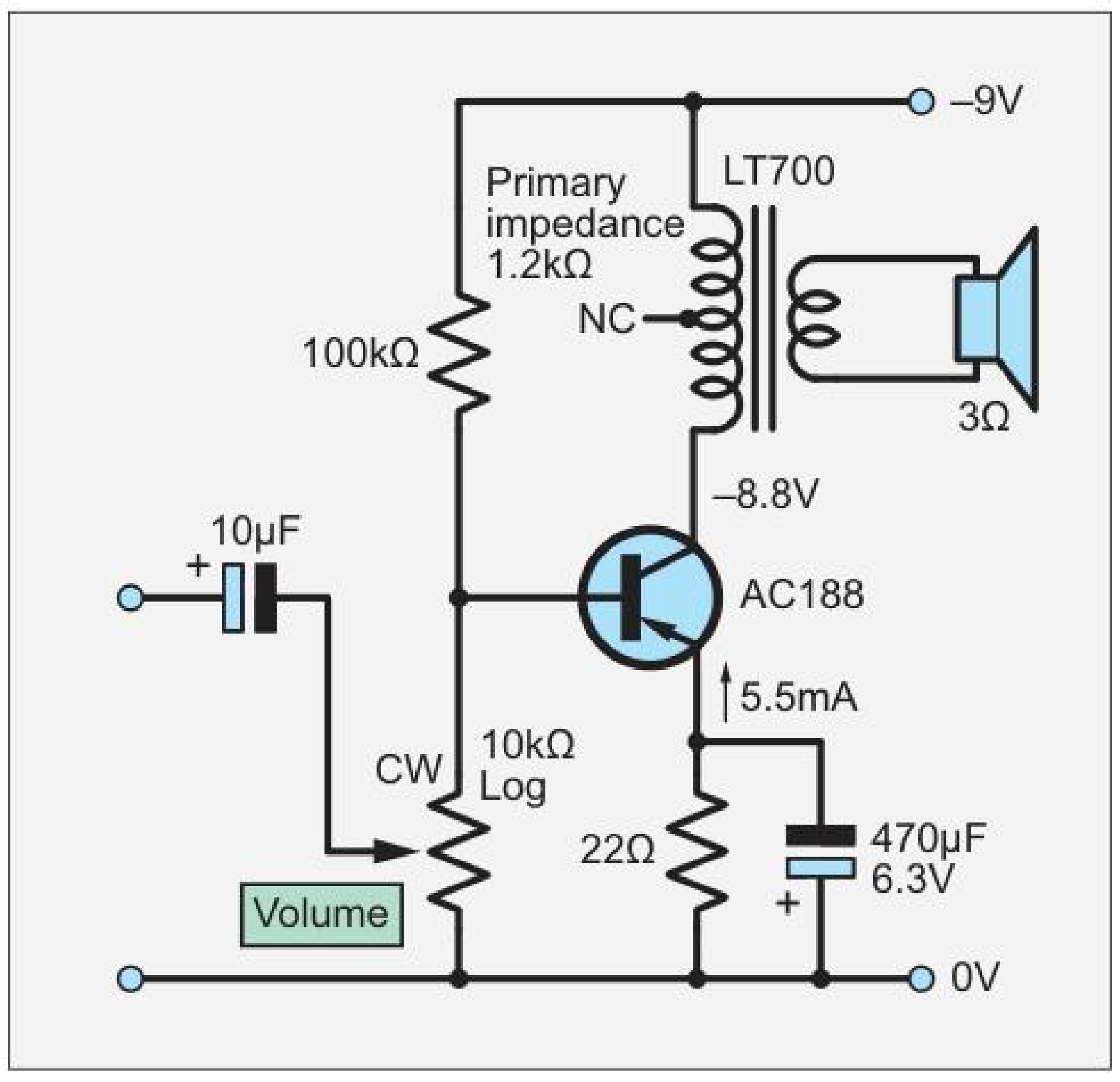
–9V
Primary impedance 1.2kΩ
LT700
NC
100kΩ
3Ω
–8.8V
10µF
+
AC188
5.5mA
CW
10kΩ Log
22Ω
470µF 6.3V
+
Volume
0V

Fig.22. Uprated and re-biased output amplifier circuit to avoid thermal runaway.

R5 from 33kΩ to 4.7kΩ to get half rail 4.5V across the collector load resistor, R6. Better than tweaking, make the circuit immune to current gain (H_{fe}) spreads by putting in a decoupled emitter resistor: 1kΩ and 22µF in the first audio stage and 22Ω and 470µF in the output.

I noticed stabilisation was applied in the audio amplifier on page 44 of *Learn About Simple Electronics*. In the radio section, I found reducing the 390kΩ resistor to 300kΩ gave more accurate biasing with 3.5V across the collector load resistor R2. After a few hours, I found that the output transistor OC71 went into thermal runaway and became permanently leaky. Interestingly, this process was kicked off by the RF emissions from touching a nearby LED lamp. I vaguely remember my OC71 getting hot in 1972, which denotes death in germanium transistors. Runaway is quite likely to occur, since the transformer secondary has a DC resistance of only 60Ω. I replaced the OC71 with a higher power AC188 (Fig.22) Also, I used a 4.7kΩ log volume potentiometer because I didn't have any 10kΩ types. I then had to reduce bias resistor R7 to 100kΩ. This set the standing current to around 5.5mA. The output was 42mW into 3Ω. These bias improvements add six extra components to the whole radio. I see now why George Dobbs omitted them in his original circuit (Fig.23), too much complexity for children. The modified Ladybird circuit is shown in Fig.24.

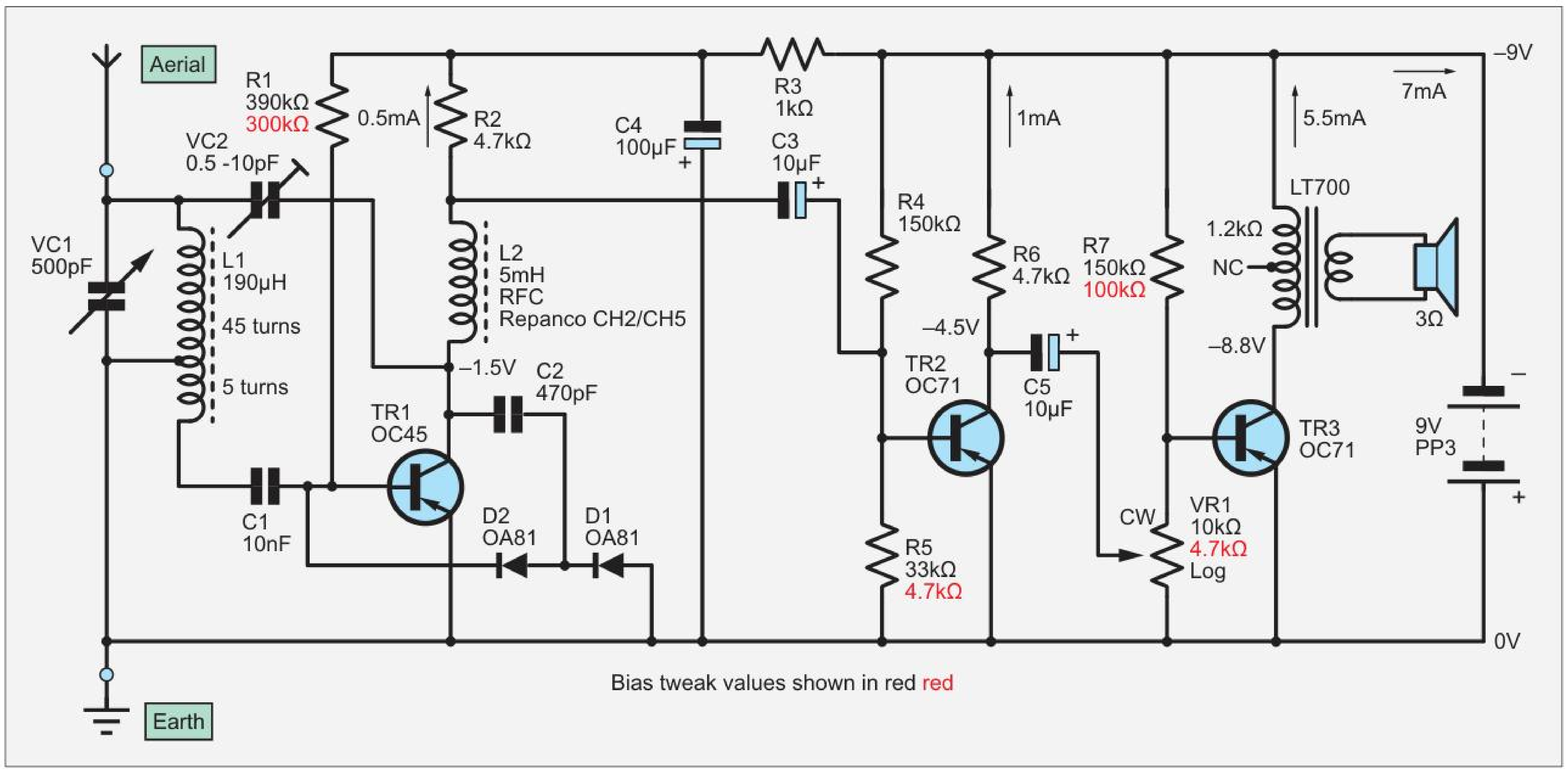
Aerial
R1 390kΩ 300kΩ
0.5mA
R2 4.7kΩ
C4 100µF
+
R3 1kΩ
C3 10µF
+
–9V
7mA
1mA
5.5mA
VC2 0.5 -10pF
LT700
R4 150kΩ
R6 4.7kΩ
R7 150kΩ 100kΩ
1.2kΩ
NC
VC1 500pF
L1 190µH
45 turns
L2 5mH RFC Repanco CH2/CH5
3Ω
–4.5V
–8.8V
5 turns
–1.5V
C2 470pF
TR2 OC71
C5 10µF
+
TR1 OC45
TR3 OC71
–
9V PP3
+
C1 10nF
D2 OA81
D1 OA81
CW
VR1 10kΩ 4.7kΩ Log
R5 33kΩ 4.7kΩ
0V
Bias tweak values shown in red red
Earth

Fig.23. Full original Ladybird radio circuit. Making it as simple as possible using just base bias made it dependent on transistor characteristics, which unfortunately made it unlikely to work without adjusting resistors, shown in red.

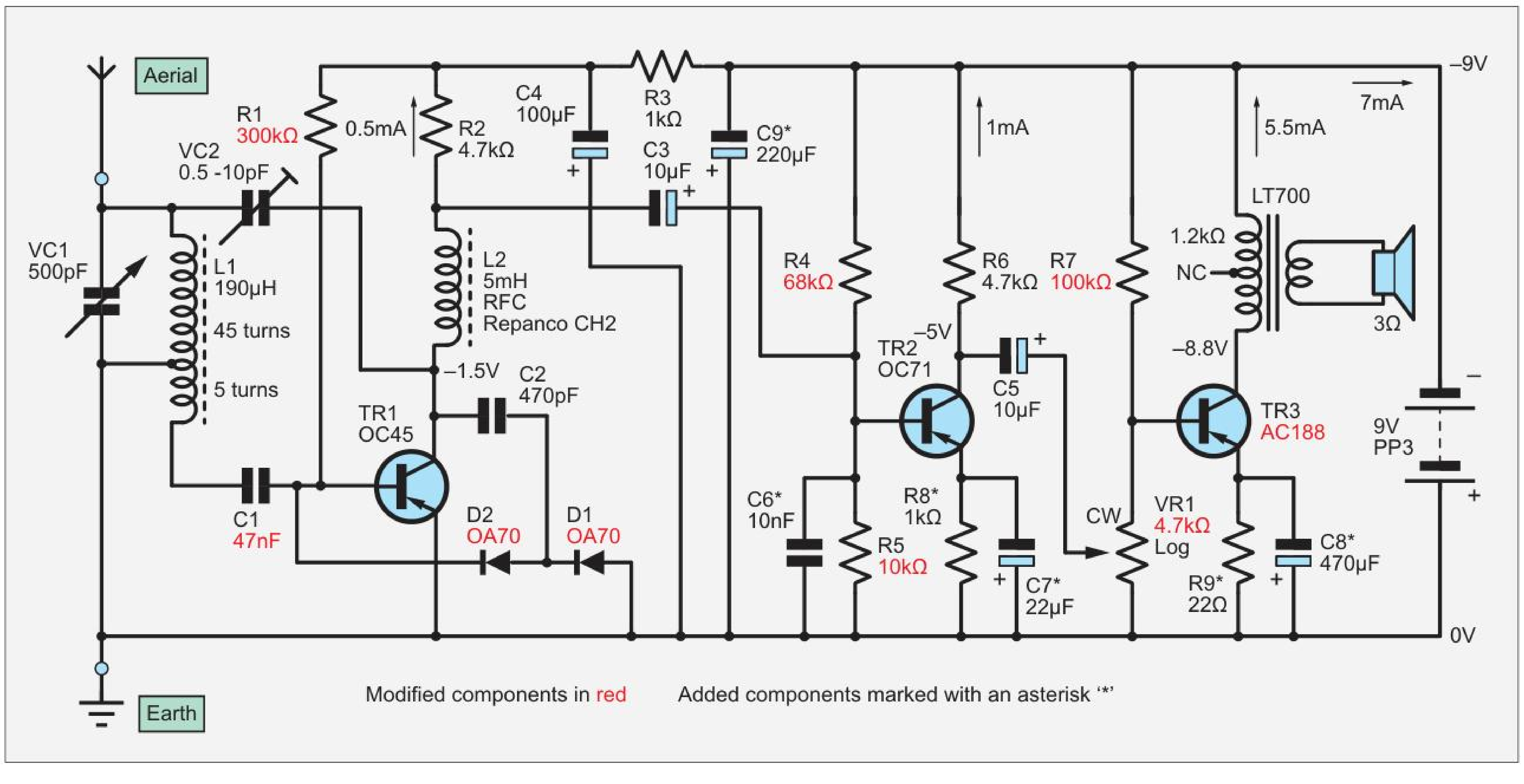
Aerial
R1 300kΩ
0.5mA
R2 4.7kΩ
C4 100µF
+
R3 1kΩ
C3 10µF
+
C9* 220µF
+
–9V
7mA
1mA
5.5mA
VC2 0.5 -10pF
LT700
R4 68kΩ
R6 4.7kΩ
R7 100kΩ
1.2kΩ
NC
VC1 500pF
L1 190µH
45 turns
L2 5mH RFC Repanco CH2
–5V
TR2 OC71
–8.8V
3Ω
5 turns
–1.5V
C2 470pF
C5 10µF
+
TR1 OC45
TR3 AC188
–
9V PP3
+
C1 47nF
D2 OA70
D1 OA70
C6* 10nF
R8* 1kΩ
R5 10kΩ
+
C7* 22µF
CW
VR1 4.7kΩ Log
R9* 22Ω
+
C8* 470µF
0V
Modified components in red
Added components marked with an asterisk '*'
Earth

Fig.24. Modified full Ladybird circuit. C1 is increased for better bass and C6 is added for RF filtering.

Radio-frequency transistor

The radio stage specified an OC45. I only had an old one which seemed to be rather noisy. I tried a 'new old stock' lower noise Toshiba 2SA53 (Fig.25) which reduced it, but there was still an additional noise. Shorting out the tuned circuit revealed a steady hiss. Initially, I didn't bother adding emitter stabilisation to this stage, since the intermediate frequency (IF) amplifier transistors specified have less H_{fe} spread, typically 50, a cut-off frequency (F_t) of 4-6MHz. Proper RF types such as the OC44, may again be too good (H_{fe} = 80, F_t = 8-12MHz). I reckon George Dobbs was inspired by some very similar circuits by A Sapciyan's *Pocket Reflex Receiver* in the August 1968 issue of *Radio Constructor* magazine (see p.27) and the *Reflex-3* in the December 1968 issue (p.302) issue. These used an AF114 or AF124 transistor, but I would be worried about audio frequency noise using an alloy-diffused germanium device.

Endless mods

Putting in proper potential divider bias (R1, R12) reduced the RF performance, because its shunt impedance damped the tuned circuit. A load resistor (R11) and coupling capacitor (C11) were also required for the detector circuit to avoid its DC output upsetting the bias. Isolating the diodes from

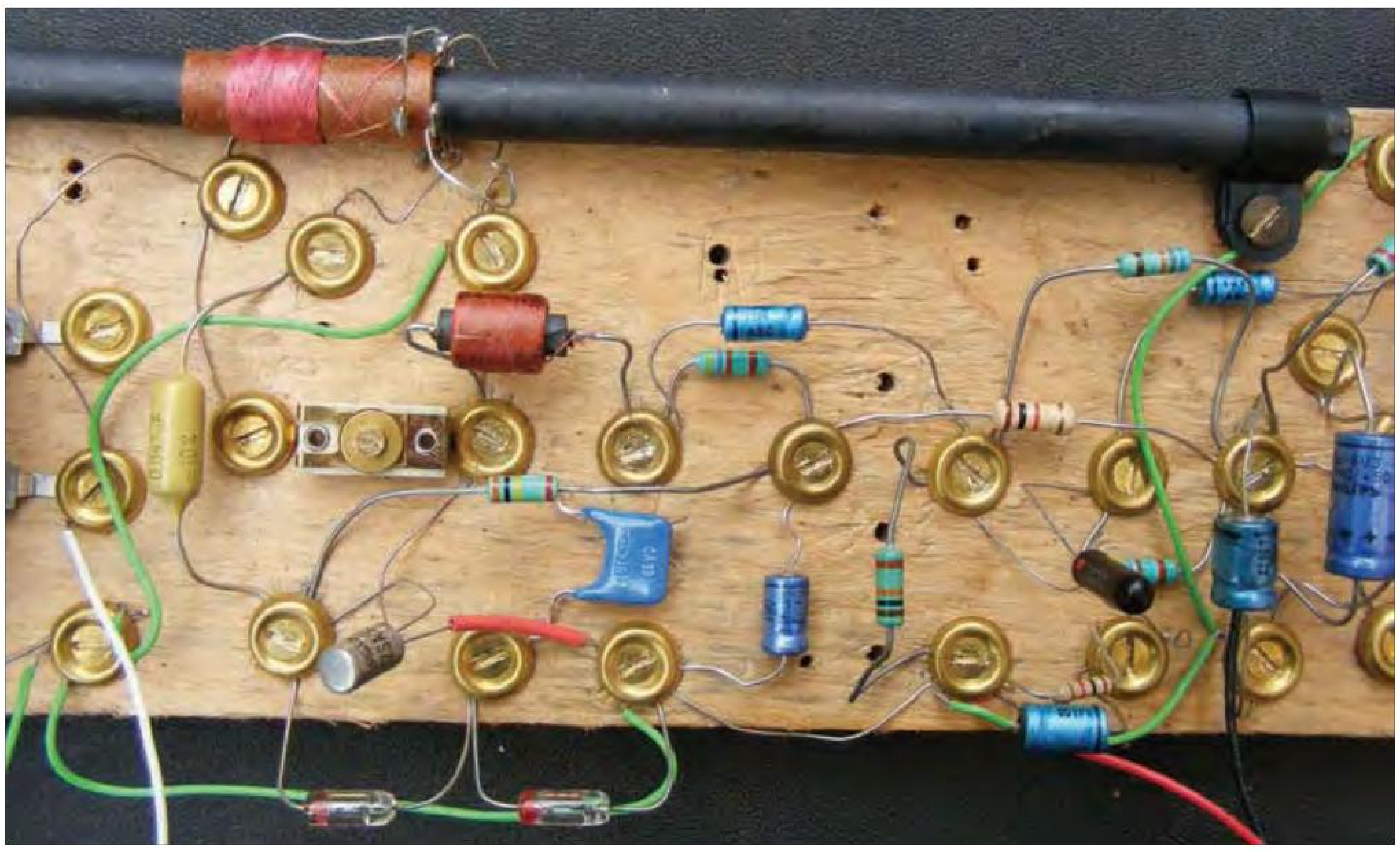

Fig.25. Long-wave version of RF stage using a 2SA53 transistor.

the DC base current removed their forward voltage bias, further reducing sensitivity, but also reducing noise (it wasn't the transistor after all). Five extra components and slightly worse RF performance, but better audio quality. The final modified circuit is shown in Fig.26. With this design, using the 8-inch LW (long-wave) ferrite rod meant the trimmer capacitor didn't peak up the gain, it seemed to reduce it. The layout was also more critical. L2 needed to be at right angles to the ferrite rod to reduce coupling, with the output being reduced if it was in-line. I realised there was a unique synergy to the original simple circuit. It is well worth adjusting the bias resistor R1 for the occasional deviant transistor.

Finally, a 220µF bypass capacitor (C9) should be added across the power rail so the radio does not burst into oscillation as the battery ages. This is good practice in any circuit. This new circuit with the other mods in the audio stages is at the limit for screw and cup construction (see Fig.34). Maybe a PCB is now needed.

Tuning capacitor

The Jackson Dilecon solid-dielectric type is no longer available. Only the single-vane 100pF type is still sold, as shown in Fig.27. However, a Plessey variable capacitor with a total capacitance of 500pF (364pF and 186pF) shown in Fig.28 can still be obtained for about £5.00. This is what I had to use. It's superior anyway, having slow-motion drive and ball bearings. Also, air-spaced capacitors have lower losses than solid-dielectric types. Since the radio can only get a couple of stations, a 50pF trimmer capacitor in parallel with a fixed 150pF capacitor could be used to save cash if you're happy to listen to only one station.

Trimmer cap

I used a 40pF mica 'postage-stamp' trimmer, although 10pF was specified, the unit I used could go low enough to just about 1pF. The tags have to be bent 90 degrees to lie flat for clamping with the cups.

Radio-frequency choke (RFC)

The original design used a Repanco 2.5mH CH1. Bourns also do a suitable type, the 2.4mH pie-wound 4666-RC from Mouser, shown in Fig.29. 5mH Repanco CH2 types are still obtainable, as shown in Fig.30. However, these seemed to measure low at 3.5mH, which is fine for the Ladybird circuit.

Ferrite rod

I just used a 75mm (three-inch) piece of standard 10mm (3/8-inch) ferrite rod with 50 turns of 36 SWG enamelled wire tapped at five turns and secured with Sellotape. This gave a total winding inductance of around 190µH. This can vary according to the grade of ferrite used. I had no idea what mine was, so this is another area where tweaking must be employed to get full tuning range. One Ladybird design fault is the ferrite rod bare wire-loop mounting technique which caused two shorted turns. I used a pair of 9.5mm plastic 'P' clips. Hand-winding coils was normal for electronics people back in the 1970s. For those who dread doing it, I have made some ready wound coils available. I recommend a longer eight-inch rod for better reception if you're not using an external aerial.

Sob story

It's sad, but I now know why my childhood radio didn't work. There were too many little things wrong which at the time I didn't know how to test for. Also, like many beginners I built the whole thing in one go without testing along the way. If I had had an older mentor with a multimeter it would have worked, because the biasing errors would have been spotted. I guess George Dobbs was using the surplus OC71s which had very low H_{fe} and were the cheapest transistor in the UK at the time. I got my mum to buy full-spec devices from Electro Value Ltd. Emitter resistors should have been used to make the design less H_{fe} dependent, or

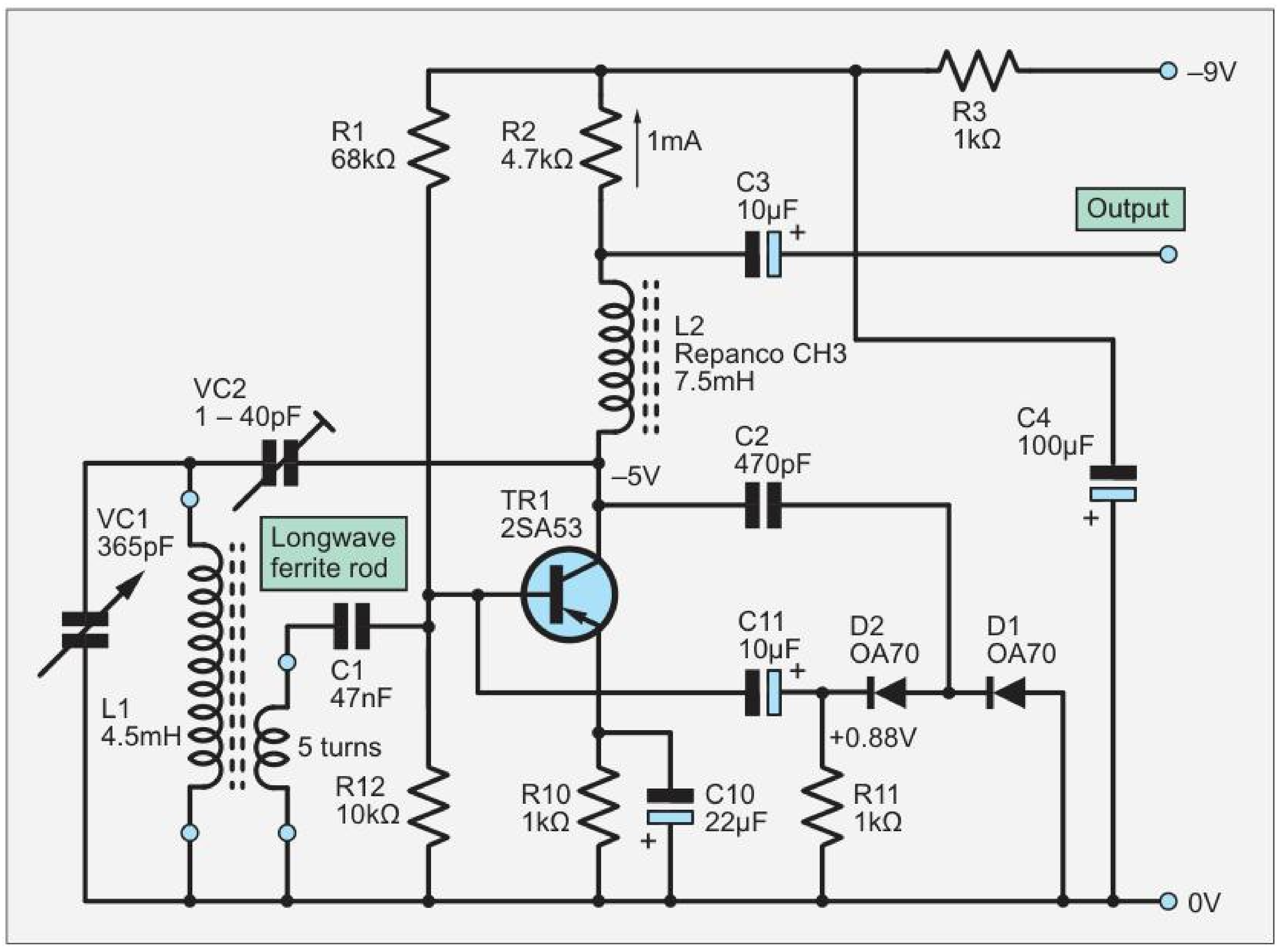

Fig.26. Modified RF circuit with lower noise.

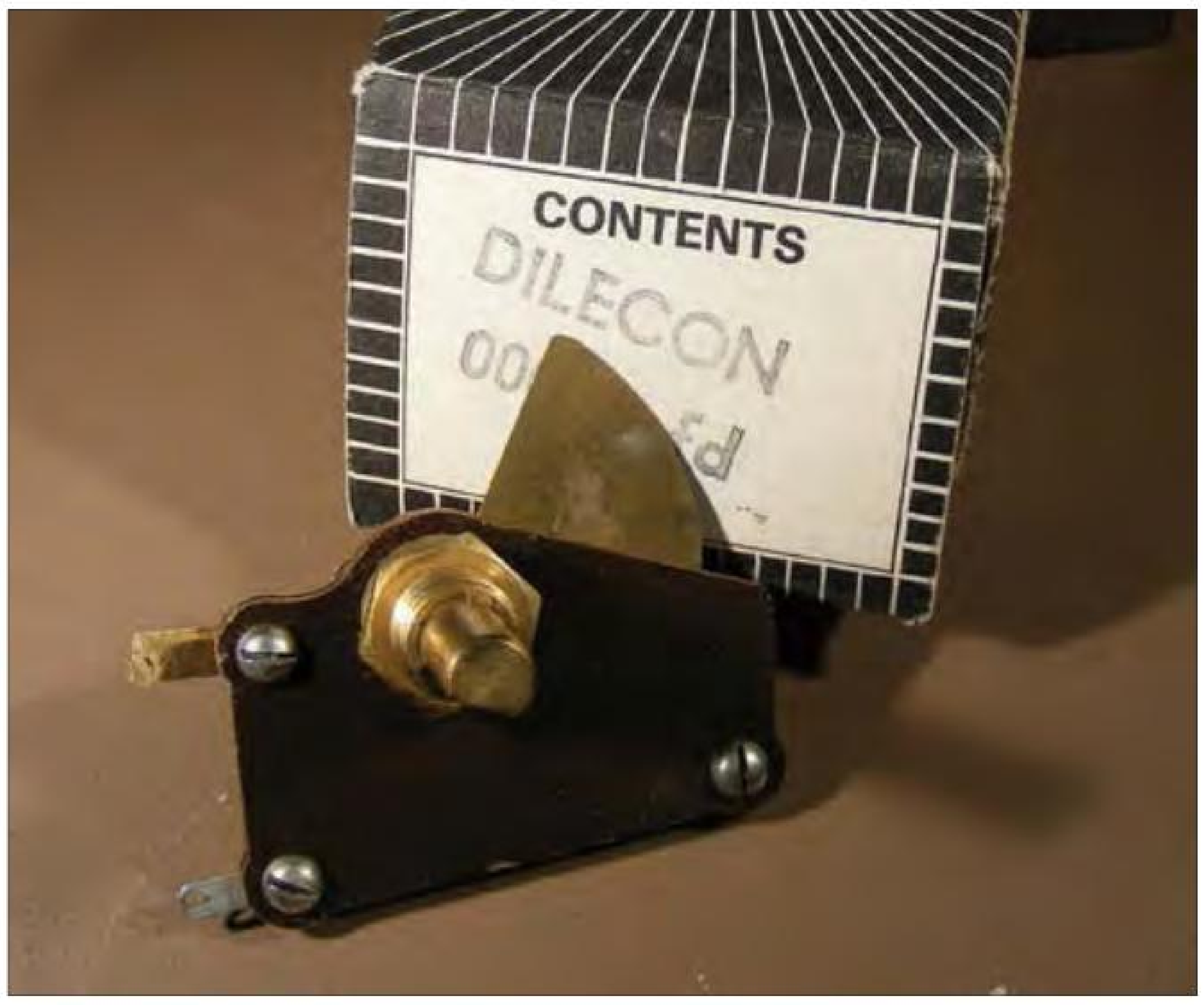

Fig.27. The original Jackson Dilecon tuning capacitor.

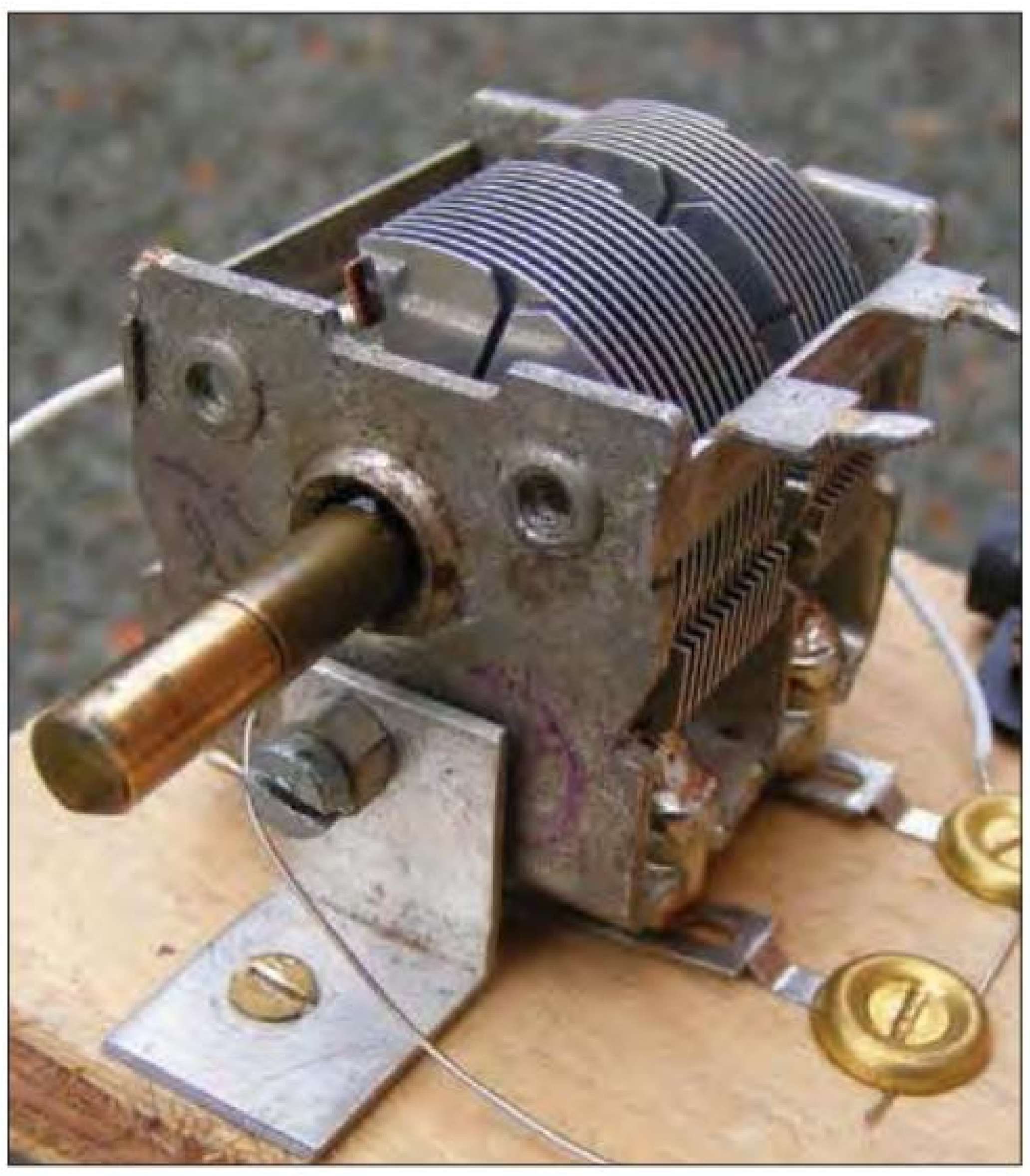

Fig.28. The recommended Plessey tuning capacitor. Still available and a mechanical work of art. Note a right-angle bracket is needed on the front with a 4BA bolt for mounting.

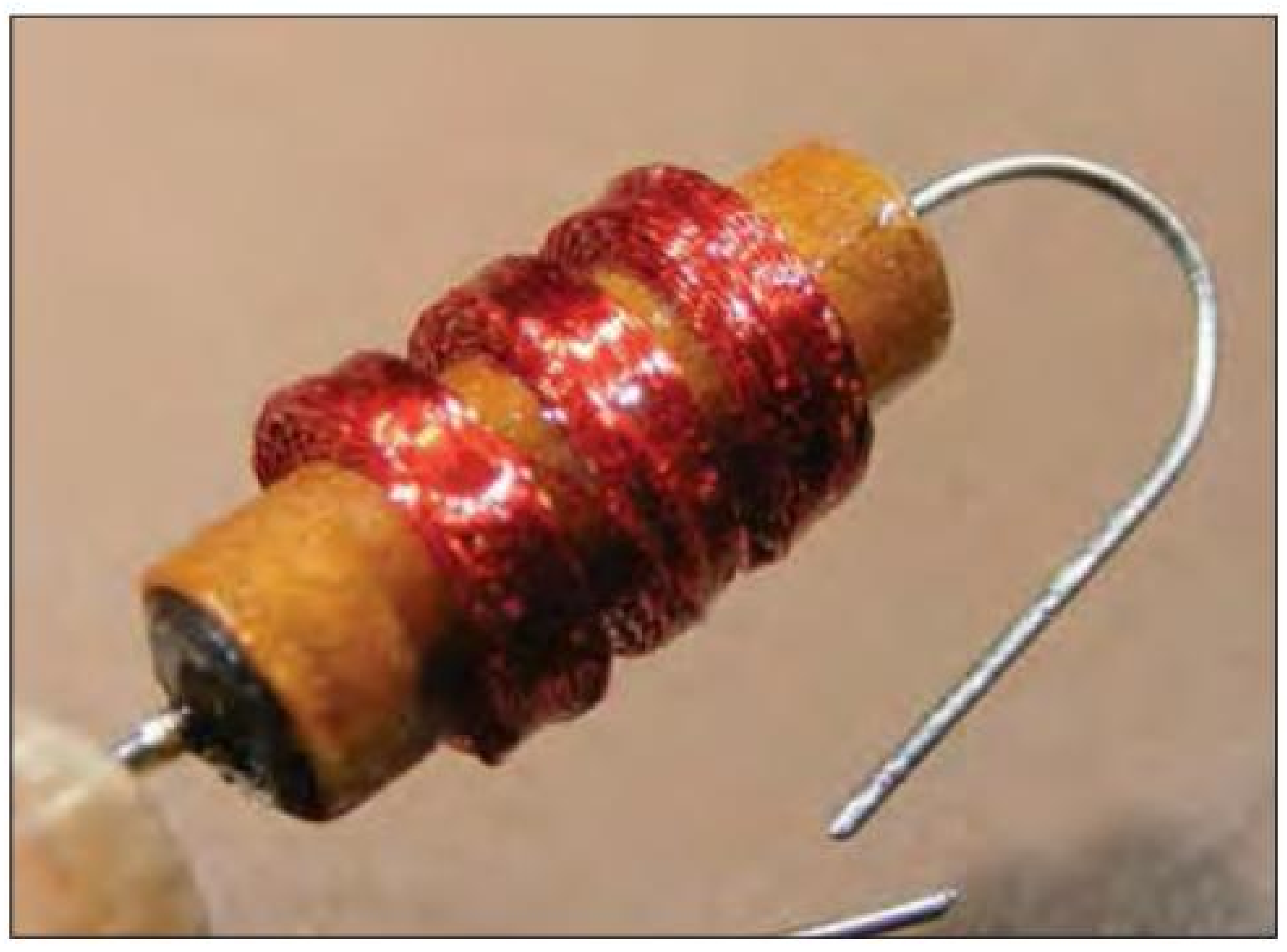

Fig.29. Mouser sell a suitable RFC (RF choke); this one is from Bourns. Note the multi-pie windings to reduce parasitic capacitance.

an additional section written on tweaking the bias resistors to get the right voltages. The mechanical solder-less construction worked surprisingly well though. I was amazed how sensitive the simple reflex circuit was when the positive feedback trimmer capacitor was peaked up just before oscillation occurred. It even worked well with no aerial and earth. With just the ferrite rod alone, BBC Radio 5 Live filled the workshop. However, apart from about ten whistles and power supply buzzes, that was all I could get. There was plenty of sensitivity, but little selectivity. The finished radio is shown in Fig.31.

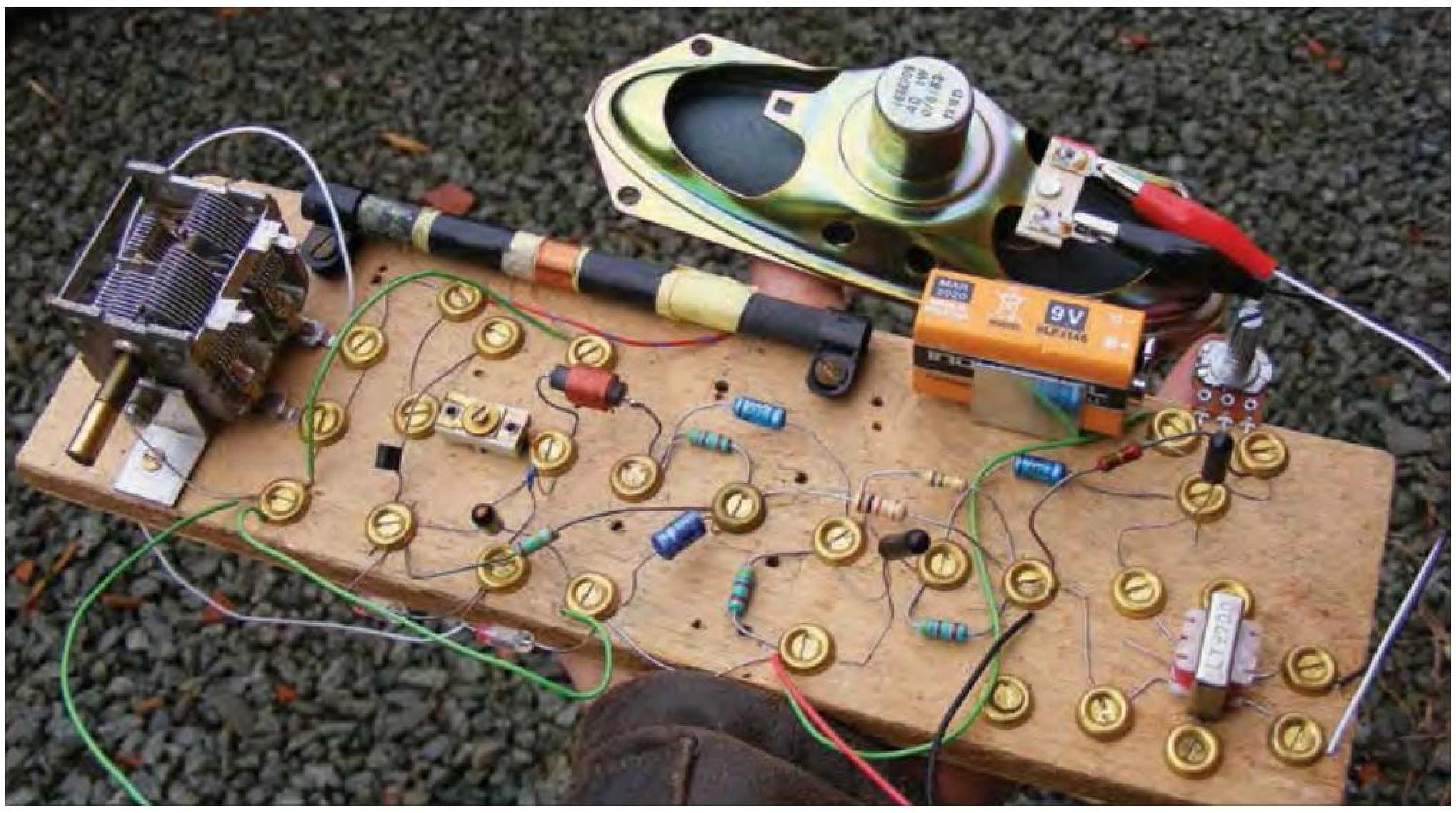

Fig.31. The finished radio – original version.

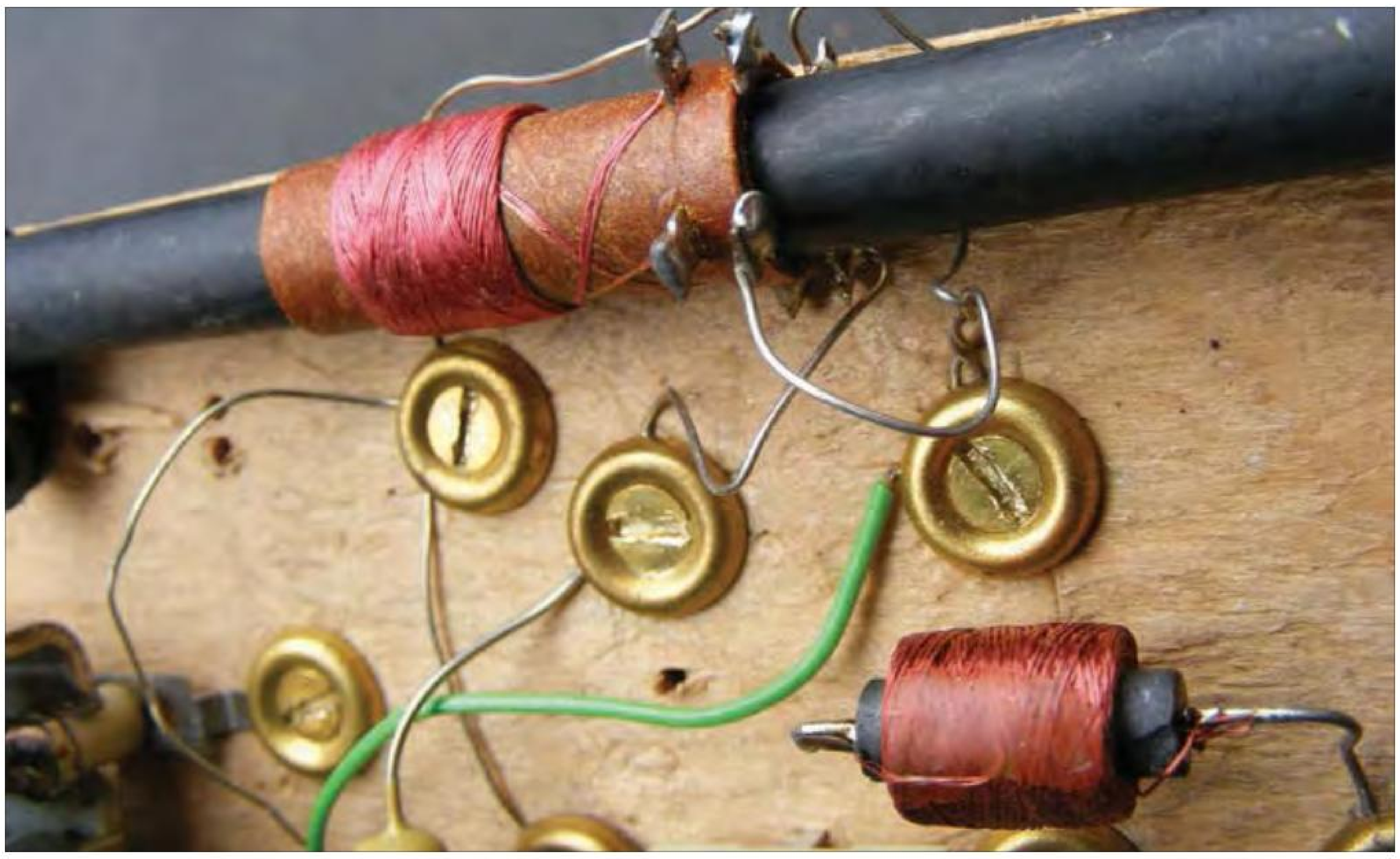

Fig.32. Long-wave aerial coil; note how the two separate windings are linked underneath to get tap.

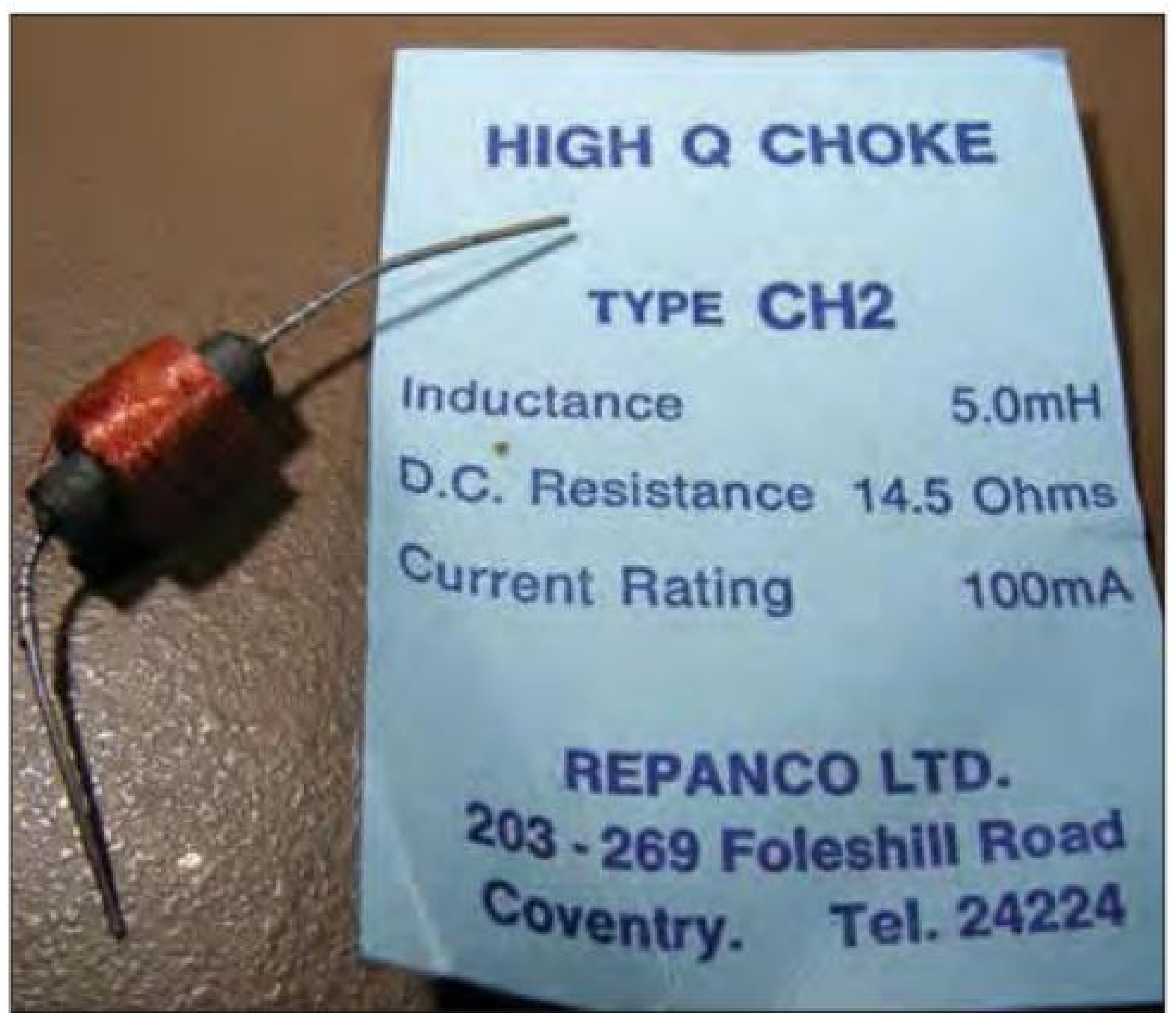

Fig.30. Repanco CH2 RFC; this uses wave winding and Litz wire to minimise losses.

Home service

I suspect most *PE* readers would prefer a long-wave version to get Radio 4 198kHz and possibly our French readers need LW as well. I was surprised that I received a station unknown to me (in mid-Wales): RTE Radio 1 from Ireland on 252kHz. In the evening, I even got a French station. To get LW requires a few changes to the tuned circuit. I used a ready-wound 4.5mH LW coil with an 8-inch ferrite rod. This consists of two separate windings which have to be joined together, as shown in Fig.32. The smaller section of the tuning capacitor was disconnected, using only the 360pF part. A reduction in tuning capacitance is also needed for the ready-wound MW coil. For LW, C1 was increased to 47nF and L2, the RFC, to 7.5mH (a CH3 type). This modified radio is shown in Fig.33 with an old sensitive Goodmans 3Ω loudspeaker. The final version with the bias mods for the reflex stage is shown in Fig.34. They're a bit more complex than the original Ladybird design, but then I can't resist trying to improve everything. (I did, however, draw the line at modifying it for silicon semiconductors.)

Consuming a miserly 7mA, I could listen to news all day with just a PP3 battery. It was also a fantastic electromagnetic interference 'sniffer', picking up emissions from my lamps and test gear 'unseen' by normal radios.

Components

All components marked with a '*' are for modifications from the original design.

Availability

I can supply all parts or kits:
Tel 01597 829102
Email jrothman1962@gmail.com

Also, a very good supplier is Birketts, who have been supporting the Ladybird and other George Dobbs designs for years. Best to phone Thursdays when Judy Birkett is often in. They don't operate online, which for this project seems entirely appropriate!

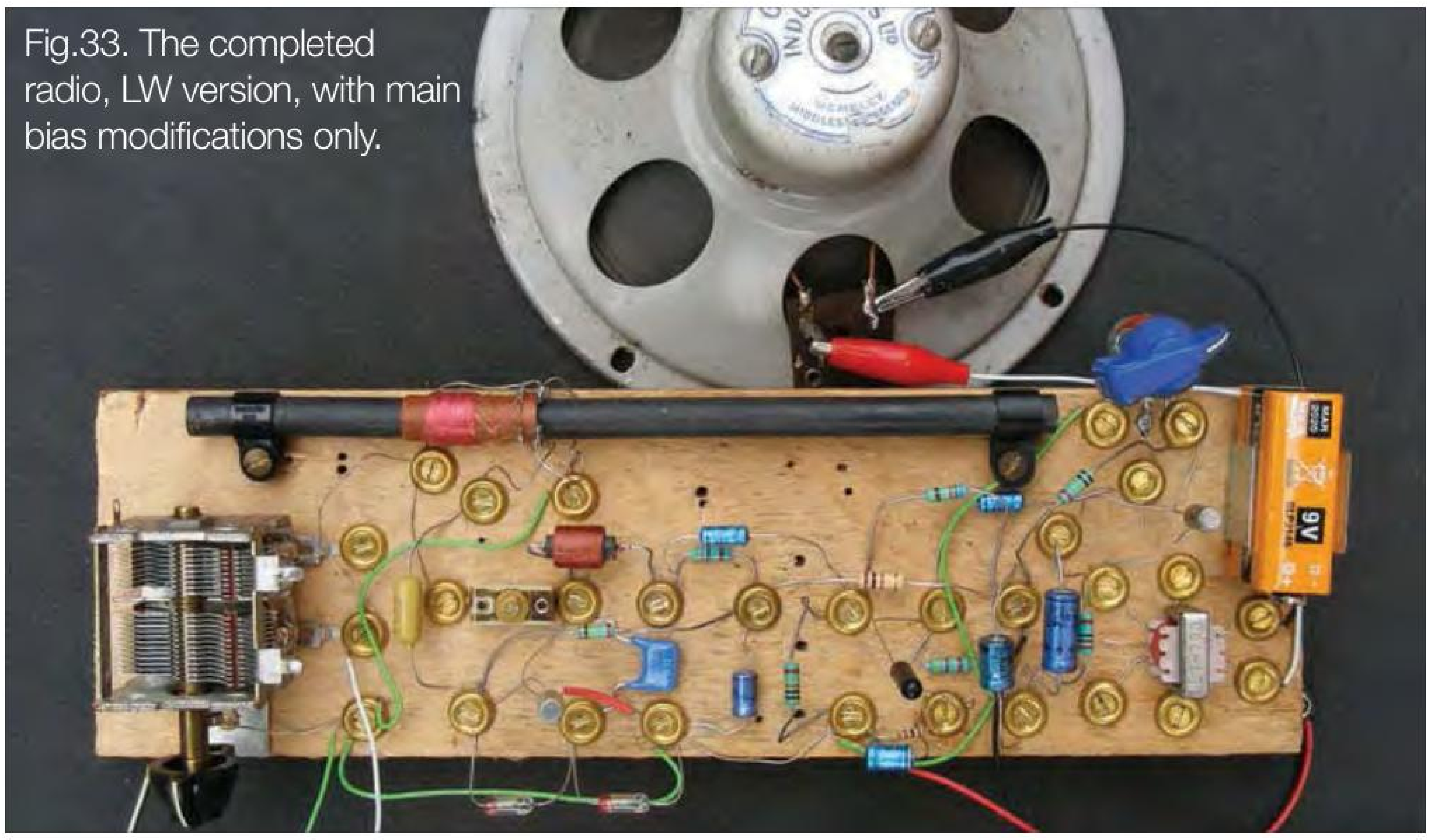
Fig.33. The completed radio, LW version, with main bias modifications only.

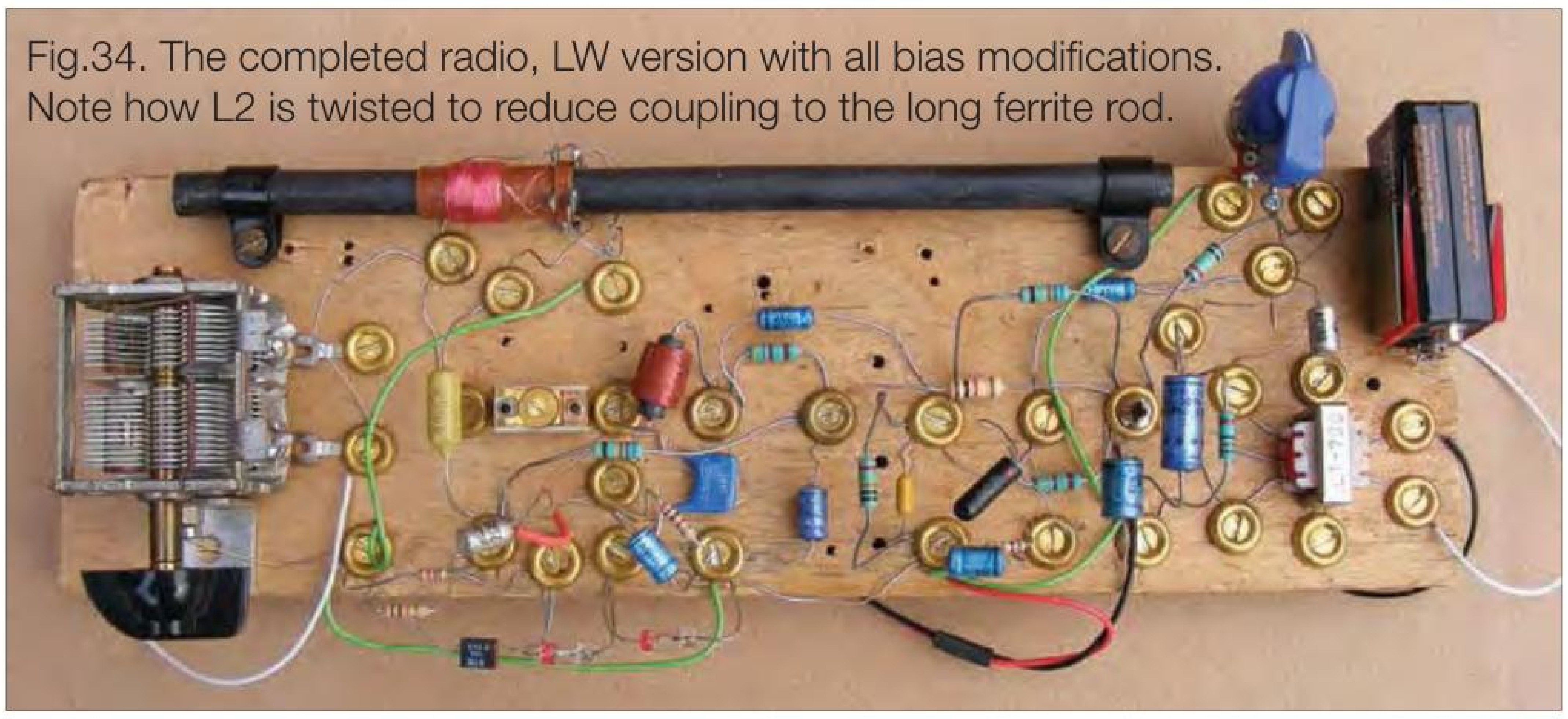
Fig.34. The completed radio, LW version with all bias modifications. Note how L2 is twisted to reduce coupling to the long ferrite rod.

J Birkett, Radio Component Suppliers, 25 The Strait, Lincoln LN2 1JF. Tel 01522 520 767

Resistors
Use big old-fashioned half or one-watt types. I mainly used Electrosil tin-oxide TR5 types with long leads. For visual authenticity use carbon composition devices; 10% tolerance is good enough.

R1 390kΩ (*300kΩ original, 68kΩ final modification)
R2 4.7kΩ
R3 1kΩ
R4 150kΩ (*68kΩ)
R5 33kΩ (*4.7kΩ original, 10k final mod)
R6 4.7kΩ
R7 150kΩ (*100kΩ original)
R8 *1kΩ
R9 *22Ω
R10 *1k
R11 *10kΩ
R12 *10kΩ
VR1 10kΩ log (*4.7kΩ log)

Capacitors.
Axial types fit best; I used the blue Mullard 017 electrolytics for appearance. Tolerance or voltage is uncritical.

C1 10nF ceramic disc (*47n C296 polyester)
C2 470pF silvered mica or ceramic
C3,5 10µF 25V
C4 100µF 10V
C6* 10n ceramic
C7, 10* 22µF 25V
C8* 470µF 6.3V
C9* 220µF 10V
C11* 10µF 10V tantalum

VC1 365 + 186 pF dual-gang Plessey with slow-motion drive.
VC2 mica trimmer 10pF, or a plastic-film

Transistors
TR1 OC45 or *2SA53 radio-frequency germanium
TR2, TR3 OC71 (TR3 * AC188 or AC153) audio-frequency germanium

Diodes
D1, D2 OA81 or * OA70, OA85, CG92, OA91, IN60 germanium point contact

Inductors
L1 Ferrite rod 3/8-inch diameter 3 to 8 inches (longer is better)
1 yard / metre of 36swg enamelled copper wire plus sticky tape
MW or LW coils with coupling winding on formers.
L2 Repanco choke 5mH CH2 for MW or * 7.5mH CH3 for LW.

I got my brass screws and cups from:
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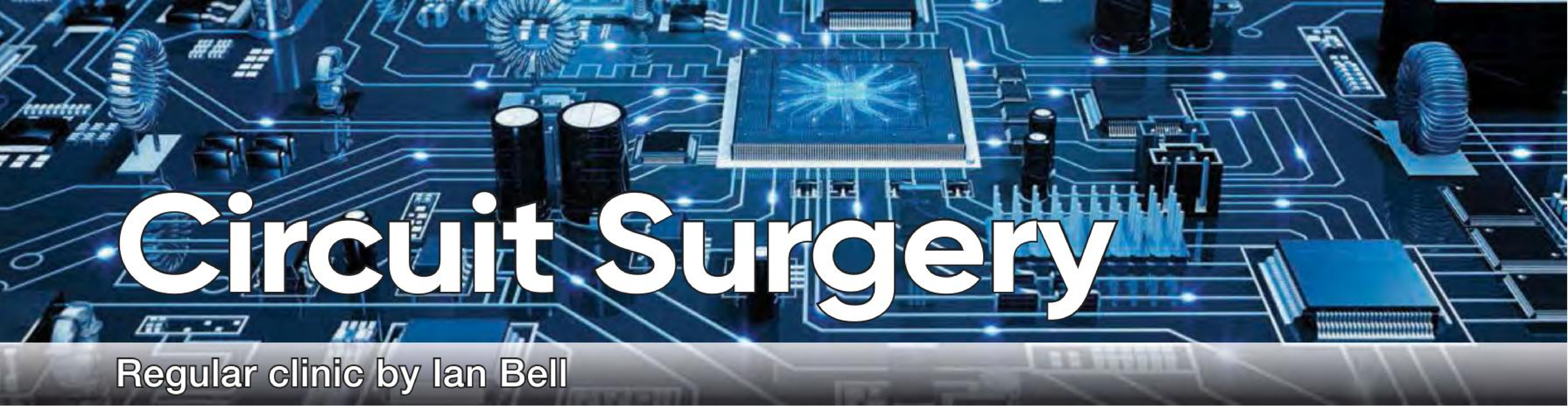


Circuit Surgery

Regular clinic by Ian Bell

Timing and metastability in synchronous circuits – Part 2

Our discussion on digital timing and metastability started a couple of months ago when we investigated a digital frequency divider simulation in Micro-Cap 12. The circuit oscillated in the simulation but worked fine as a physical circuit. The simulated behaviour was due to the fact that all the gates in the simulation had exactly the same delay. This set up the conditions for oscillation, which would be unlikely in a real circuit – however, the simulation highlighted the fact that the circuit could potentially suffer from timing problems in a real implementation.

Micro-Cap 12 forum

On the subject of Micro-Cap 12, we discovered that an online user's forum has been started recently: 'Micro-Cap EDA Users' at **mc12.createaforum.com**

Readers interested in using this software may find it a useful resource. This once-pricey software was made freely available in July 2019 after development stopped, so there is no longer official support.

Recap on synchronous circuit timing

The divider circuit was relatively unusual in that it was designed using a minimum number of NAND gates, using asynchronous design techniques, rather than just using an existing flip-flop. So last month we looked at timing issues in the much more common context of synchronous digital circuits. Synchronous circuits are controlled by a clock signal – a regular train of pulses which controls the overall timing of the circuit. Even if a synchronous circuit has a complex overall structure, it fundamentally comprises register-to-register transfers, as shown in Fig.1 – data held in register 1 (R1) is processed by the combinational logic (CL) and the result is stored in R2. On each clock cycle, R1 loads new data to be processed, and R2 stores the result of processing the data that was held in R1 in the previous clock cycle.

The circuit in Fig.1 is not infinitely fast. There is a delay from when the active clock edge occurs to when the register's output change (T_{DR}) and delays from when the combinational logic's inputs change to when we can guarantee that its outputs are correct. We also have to consider that when the data changes, the flip-flop's internal circuitry takes time to settle in response to that change. If the clock is activated too close to a data change, the flip-flop may not function correctly (we say a timing violation has occurred). It may load the wrong value or go metastable, potentially resulting in a much longer than normal delay before the output changes. To help prevent timing violations, flip-flops are specified by a setup time (T_{Setup}) and a hold time (T_{hold}) – the time before and after the clock edge during which the data must not change in order to ensure correct operation.

Timing violations

As discussed last month, for the circuit in Fig.1, the minimum clock period must be greater than $T_{DR} + T_{DC} + T_{Setup}$ to make sure that the data loaded into R2 is valid. We can ensure this in a synchronous circuit *by design*, which means that the circuit will not suffer timing violations. This is not necessarily easy, particularly in large designs, where there are performance requirements which demand high clock rates. Professional design tools for large digital circuits (eg, FPGA design) include timing analysers to help identify timing problems. Sources of timing issues are more complex than just the clock period condition we mentioned above. For example, in a large design the clock will not arrive at each flip-flop at exactly the same time (this is called clock skew), which can also cause timing violations. Nevertheless, it is possible, with some effort, to ensure that timing violations will not occur in a synchronous circuit with a single clock.

The 'guaranteed by design' does not apply when we have external asynchronous signals – they can change any time in the clock cycle, which means it is possible for them to change close enough to the active clock to cause timing violations. Similarly, in circuits with multiple clocks (clock domains) there is a possibility of timing violations when signals cross clock domains. There is a period of time as the data changes (metastability window, T_0) when clocking the latch will result in metastability (see Fig.2 and Fig.3). If metastability occurs, the latch will take an amount of time, called the 'resolution time' (T_R), before it returns to one of the stable states. In theory, this could be infinite, but in practice it is more likely to be in a range of up to about ten times the propagation delay (T_{DR}). For asynchronous signals we have no control over the relative signal timing, so we cannot guarantee to prevent metastability. We have to deal with it in terms of probability, which we will discuss in more detail shortly.

Metastability: philosophy and analogy

Before looking at a metastability probability in circuits it is worth looking

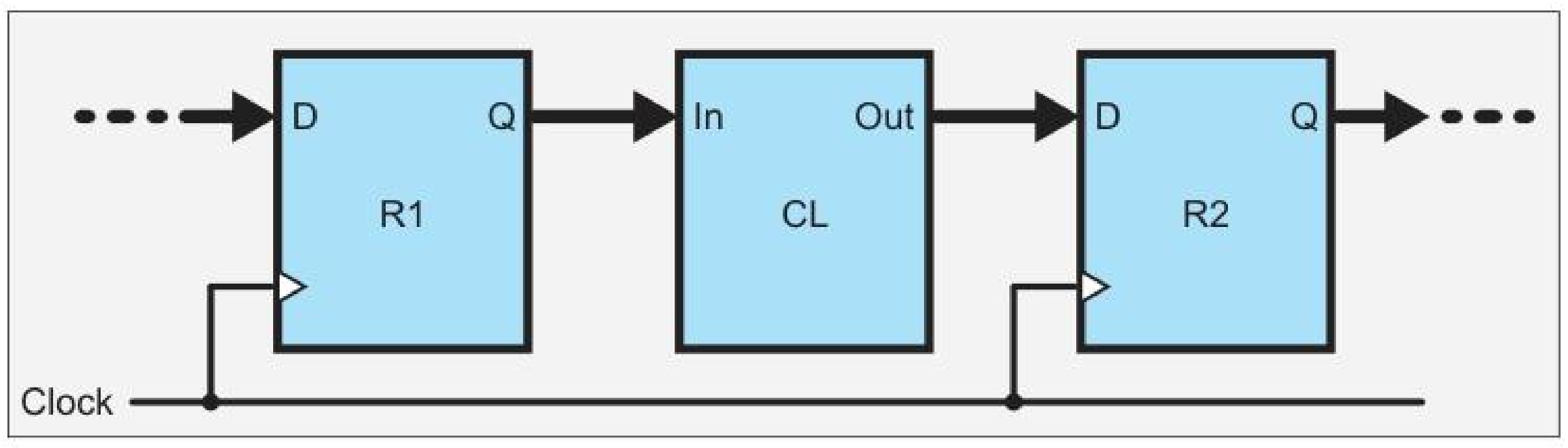


Fig.1. Register-to-register transfer (R1, R2) via a block of combinational logic (CL) is the key structure in a synchronous circuit.

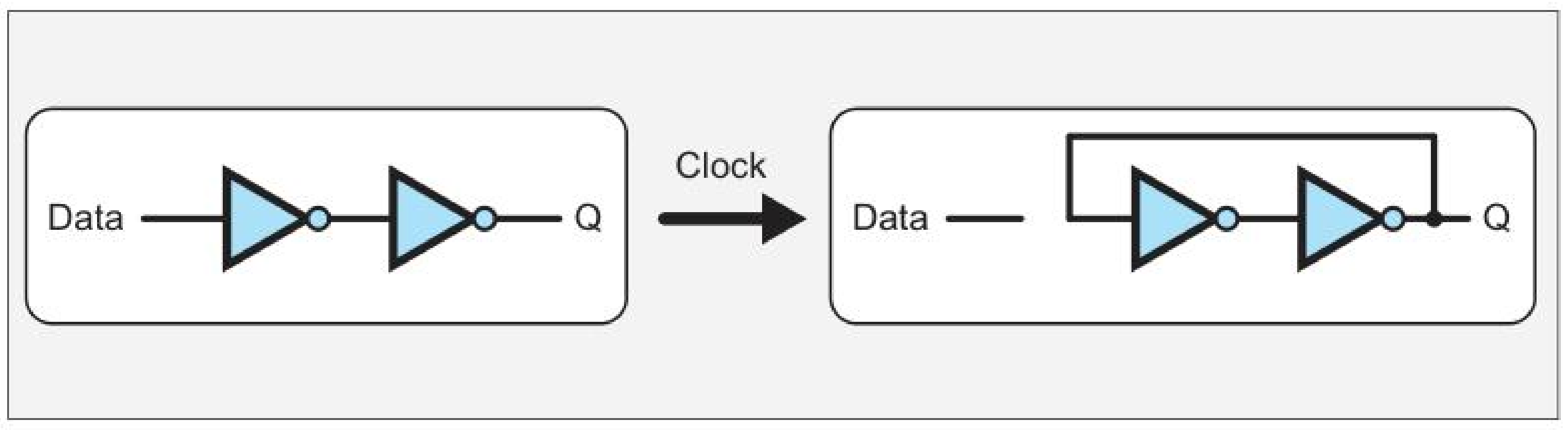


Fig.2. A Latch circuit captures a 1 or 0 in a storage loop. Metastability occurs if it captures an intermediate voltage.

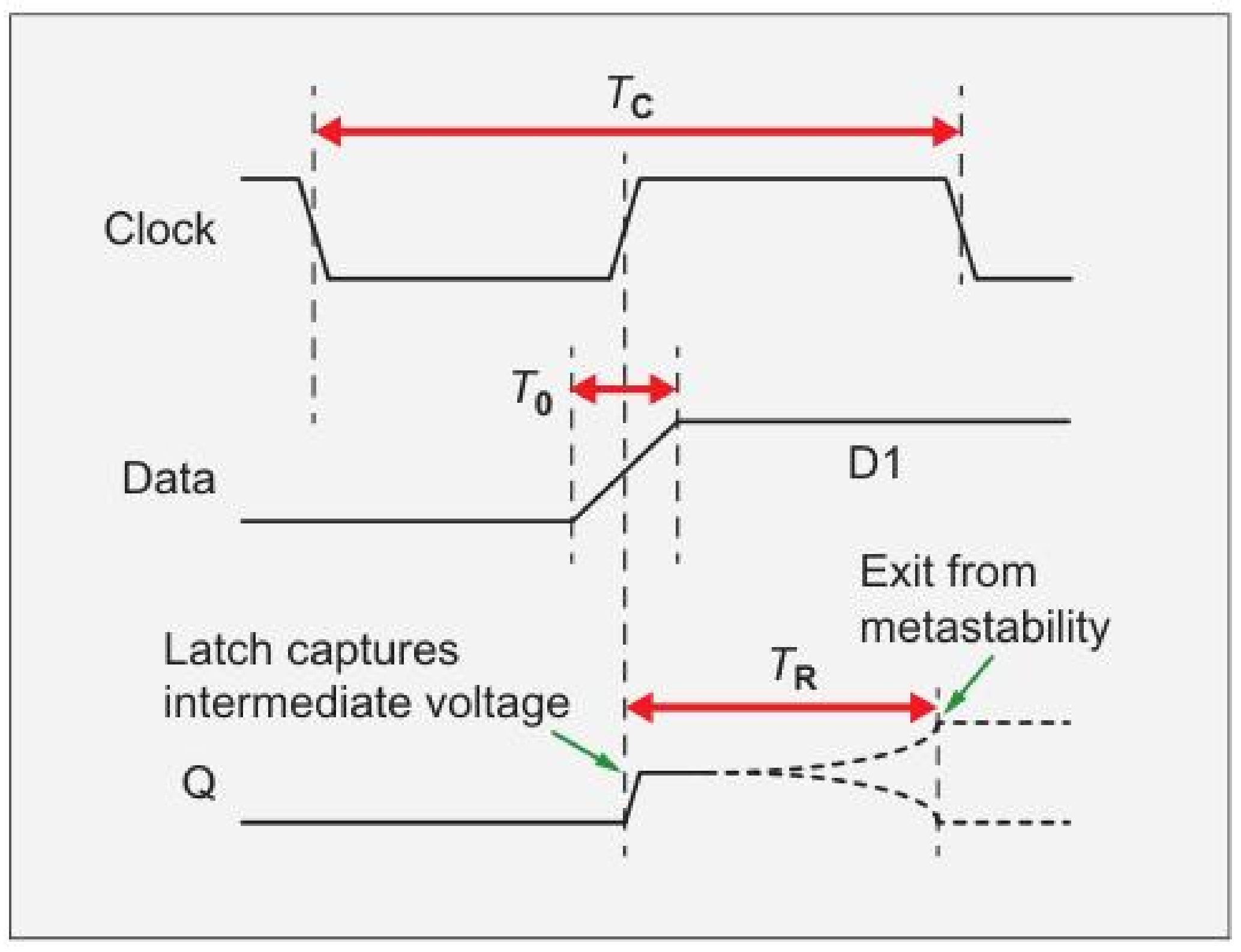
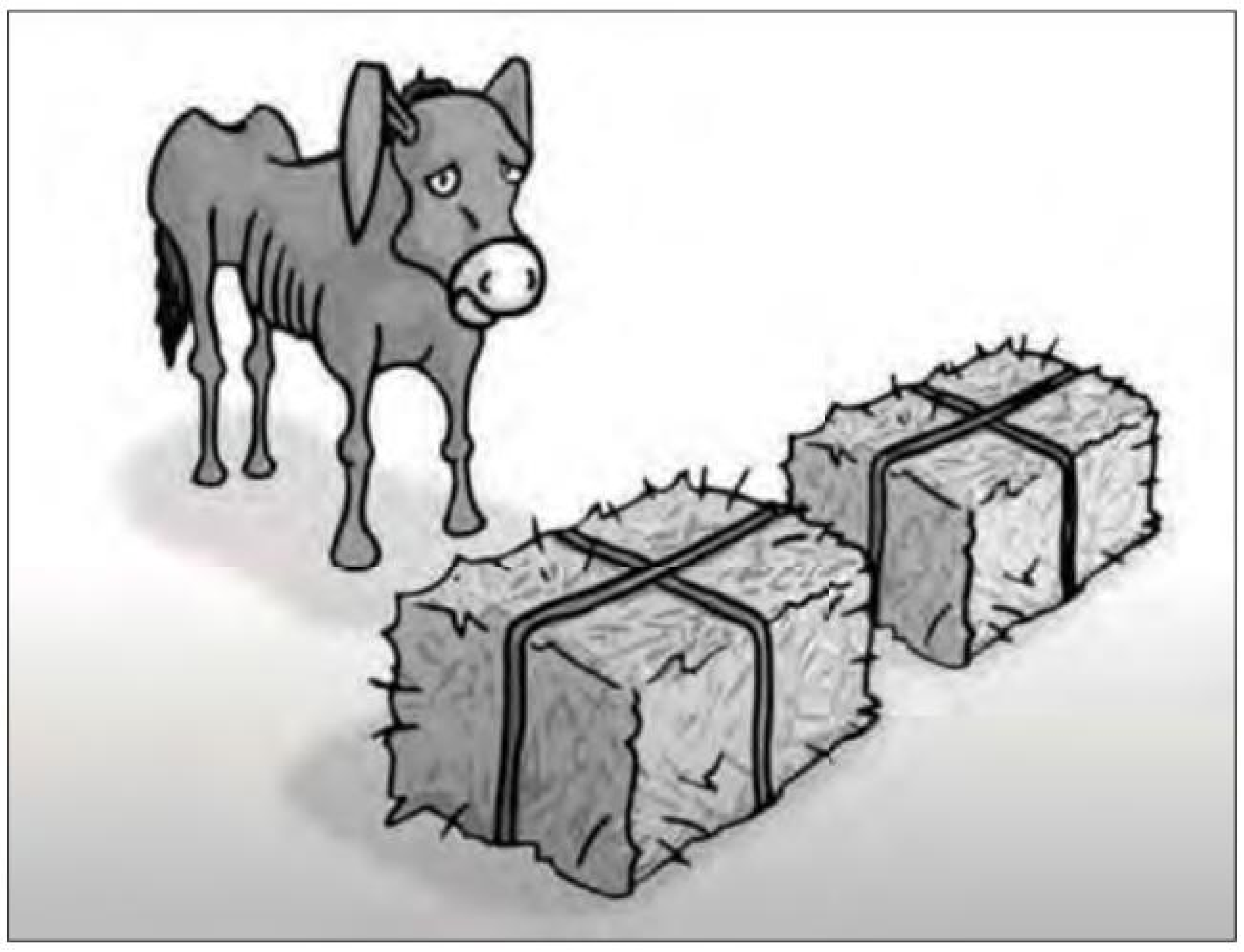


Fig.3. Latch metastability waveforms.

at an analogy or two. First, last month we noted that metastability is like flip-flop indecision – it gets stuck half-way between 0 and 1 and takes much longer than usual before it finally settles to one of the stable states. This is similar to a paradox in philosophy known as 'Buridan's ass' (donkey). The idea is that an animal (the donkey) is positioned exactly halfway between two equally desirable items of food or drink and therefore is unable to decide which one to consume – it takes so long to make up its mind that it dies of hunger or thirst. As well as featuring in philosophical discussions on reason and determinism from antiquity (predating Buridan) the idea has been used numerous times in popular culture. For more information, see the Wikipedia page on Buridan's ass (**http://bit.ly/pe-apr21-ass**).



Buridan's unfortunate ass (donkey) – courtesy of Julian Mayers, YouTube.

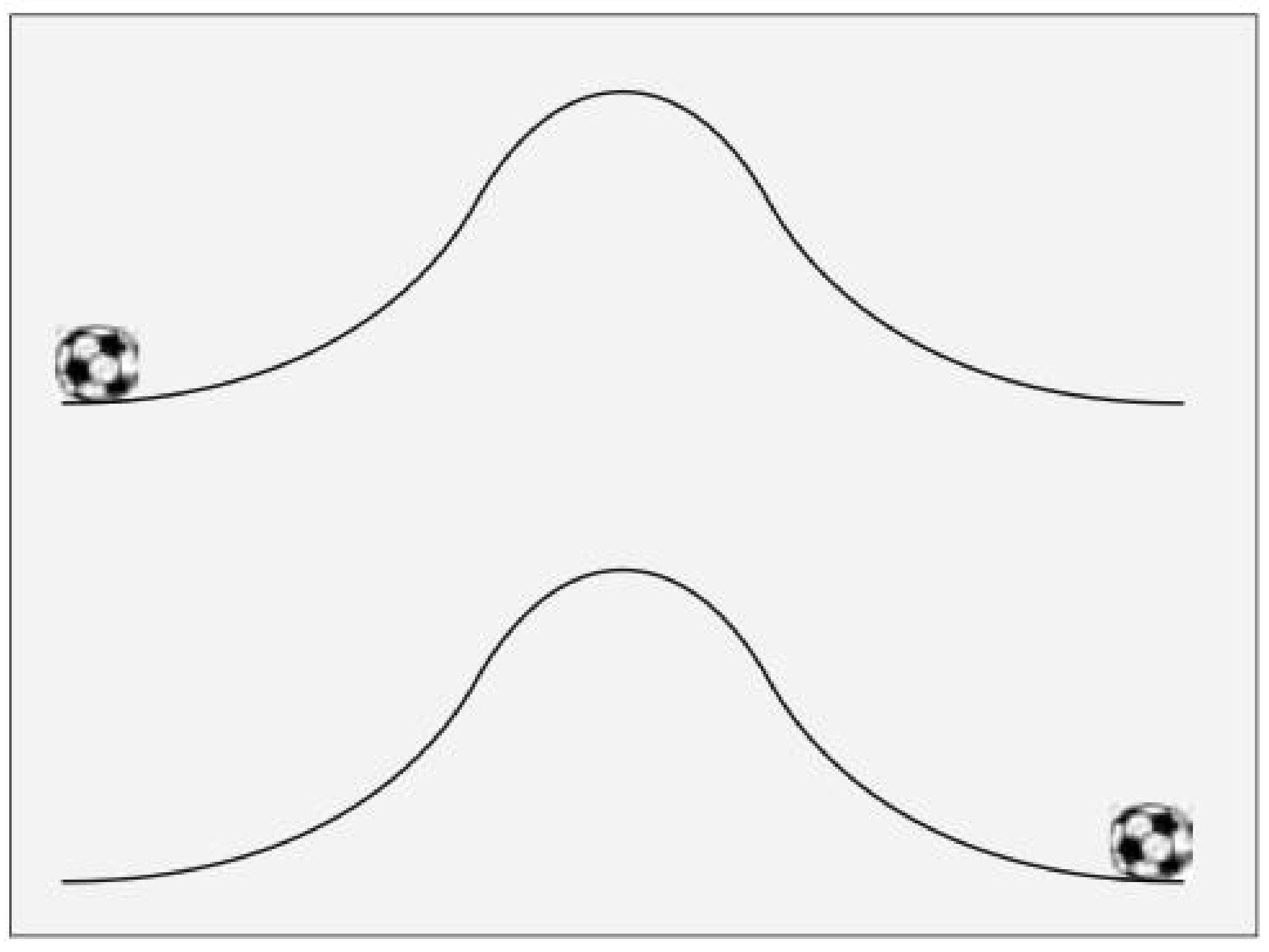


Fig.4. The ball and hill analogy – there are two stable states on the flat on either side.

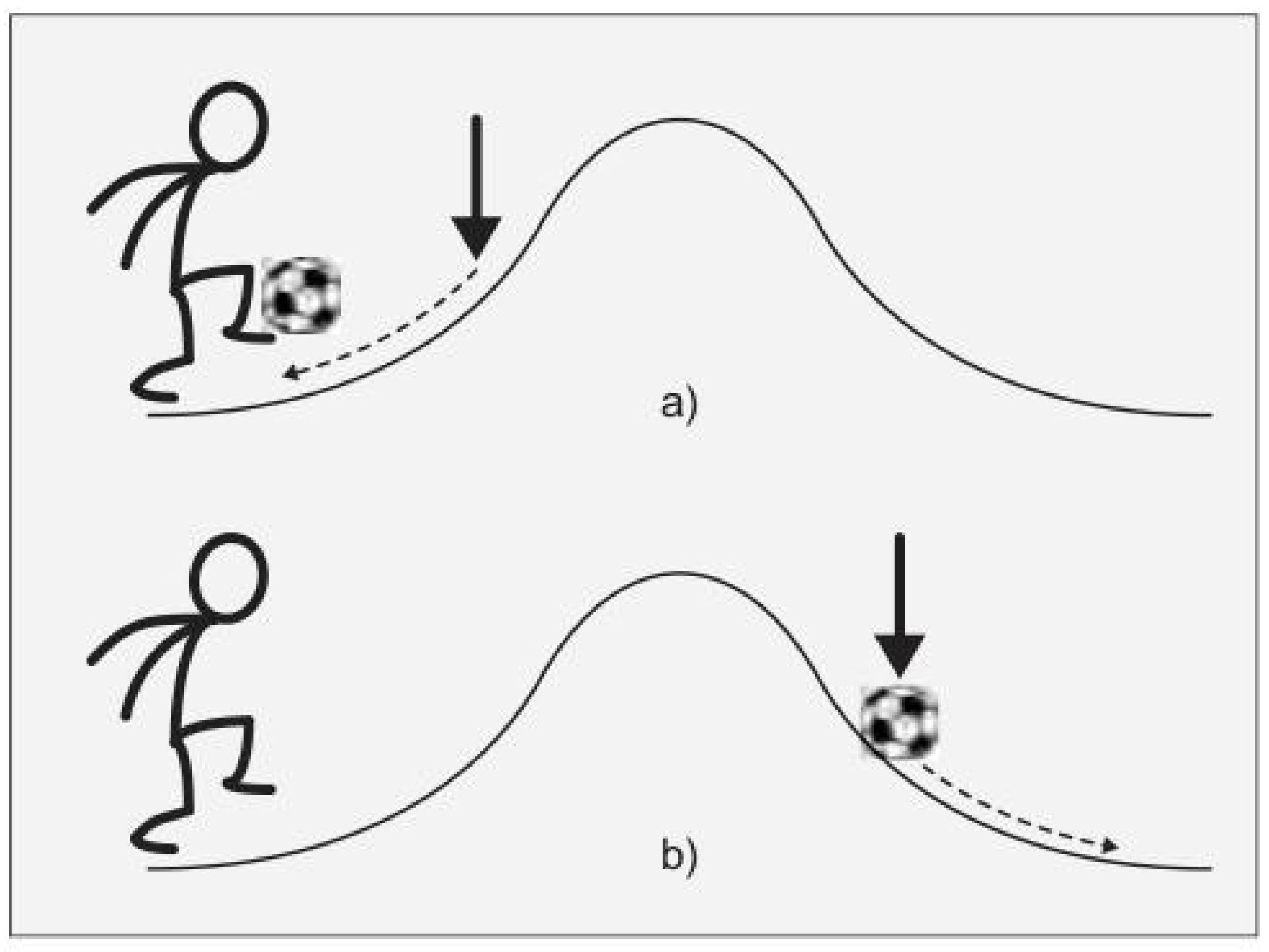


Fig.5. Analogy to normal flip-flop operation – the ball lands close to the stable state and quickly attains a stable state.

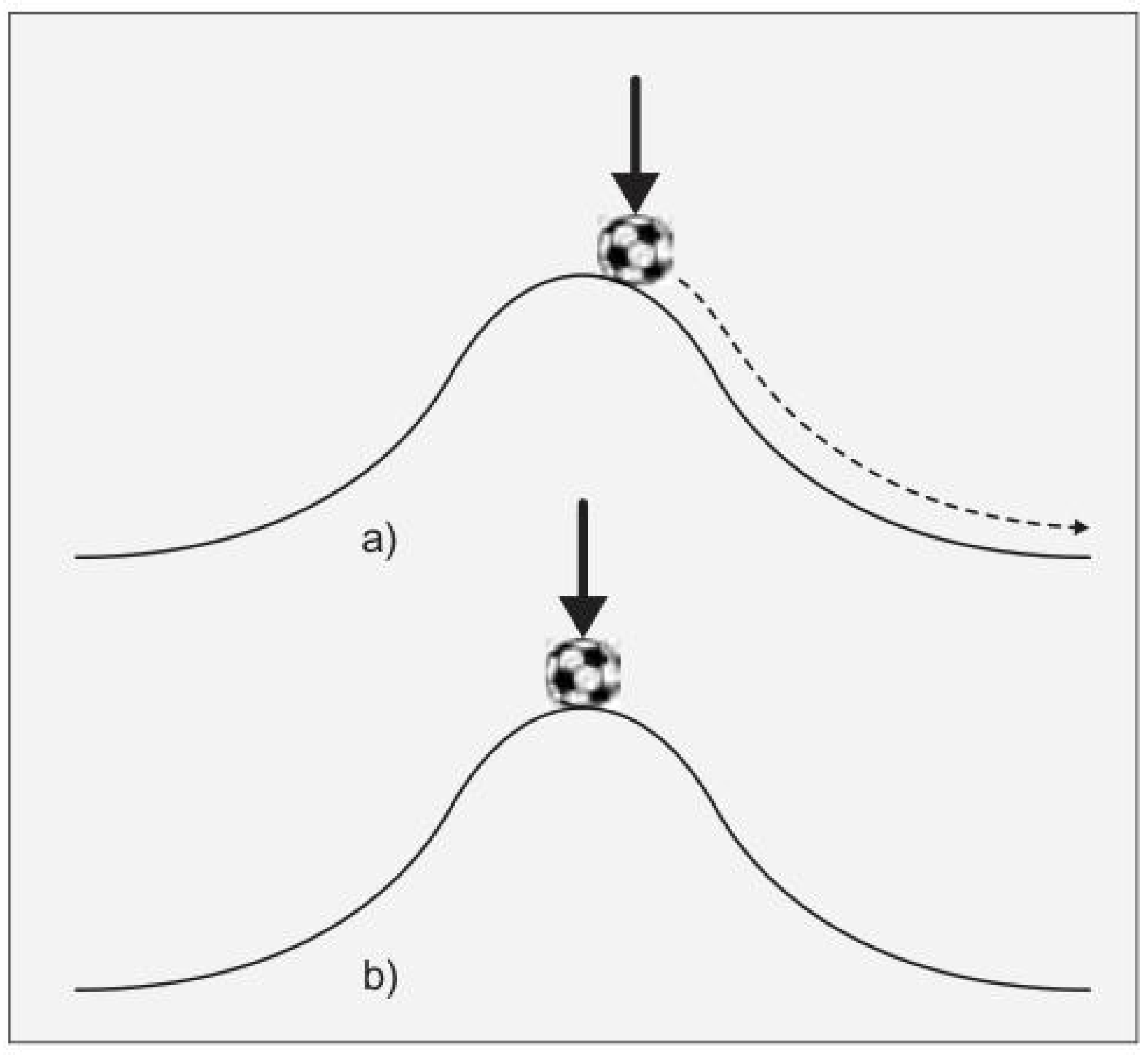


Fig.6. Analogy to metastable flip-flop operation – the ball lands close to (a), or exactly on (b), the top of the hill and takes a long time to return to a stable state.

The second analogy – the ball and hill – is commonly used to help discuss metastable circuits. It helps us understand the variation of resolution time with input timing. The idea is illustrated in Fig.4. The ball can be in one of two stable positions on either side of the hill – this corresponds to the latch circuit holding a 0 or a 1. Attempting to store a new value in the latch corresponds with kicking the ball. To properly reload the same state the ball receives a small kick and quickly rolls back from the unstable position on the slope to the original stable state (Fig.5a). To cleanly change state it receives a large kick, lands low down on the other side and quicky rolls to the other stable position (Fig.5b).

This analogy is not based on the detailed physics of kicked balls – we assume the ball drops vertically onto the hill. If the ball receives an intermediate-strength kick, corresponding with a latch storing an intermediate voltage part way between 0 and 1, it lands near the top of the hill. It will take much longer to roll to a stable state (Fig.6a), or, in the most extreme case the ball will balance exactly on the hill-top and take a potentially infinite time to reach one of the stable states (Fig.6b).

Circuit analysis

The inverter loop shown in Fig.2 captures two voltages – on the output of each inverter when the clock occurs. Normally, one inverter is at logic 0 and the other at 1, so the voltage difference between the two outputs (V_D) is relatively large. However, if the data is changing at the time of the clock, as shown in Fig.3, the loop will capture a small voltage difference. We can model what happens by considering the inverter loop as two amplifiers connected to RC circuits (wiring and inverter input and output capacitance and resistance) – inverters act like amplifiers with intermediate input voltages (see Fig.7). Analysis results in a differential equation, but we'll not go into the full details of the maths here. However, readers familiar with RC charging may not be surprised to learn that the solution is an exponential function relating V_D at time t after the clock edge to the initial voltage difference captured by the loop (V_{D0}). The smaller V_{D0} is the longer it takes for the latch to get back to a normal state – this corresponds with the ball landing closer to the top of the hill in the analogy discussed above.

In terms of digital circuit design, we would like any flip-flop that happens to go metastable to recover sufficiently quickly not to cause any problems. Typically, this means within one clock cycle, with relevant parameters such as delays and setup time taken into account, in a similar way to our earlier discussion on maximum clock frequency. This sets a maximum resolution time (T_R) which we can tolerate. Fig.3 shows two possible voltage waveforms on the latch output (for equal but opposite initial voltages). This is extended in Fig.8 to show a range of waveforms resulting from different initial voltages. The latch exits from metastability when the voltage difference (V_D) exceeds the minimum which can be considered as 'normal' latch operation – with digital 0 and 1 on the latch outputs

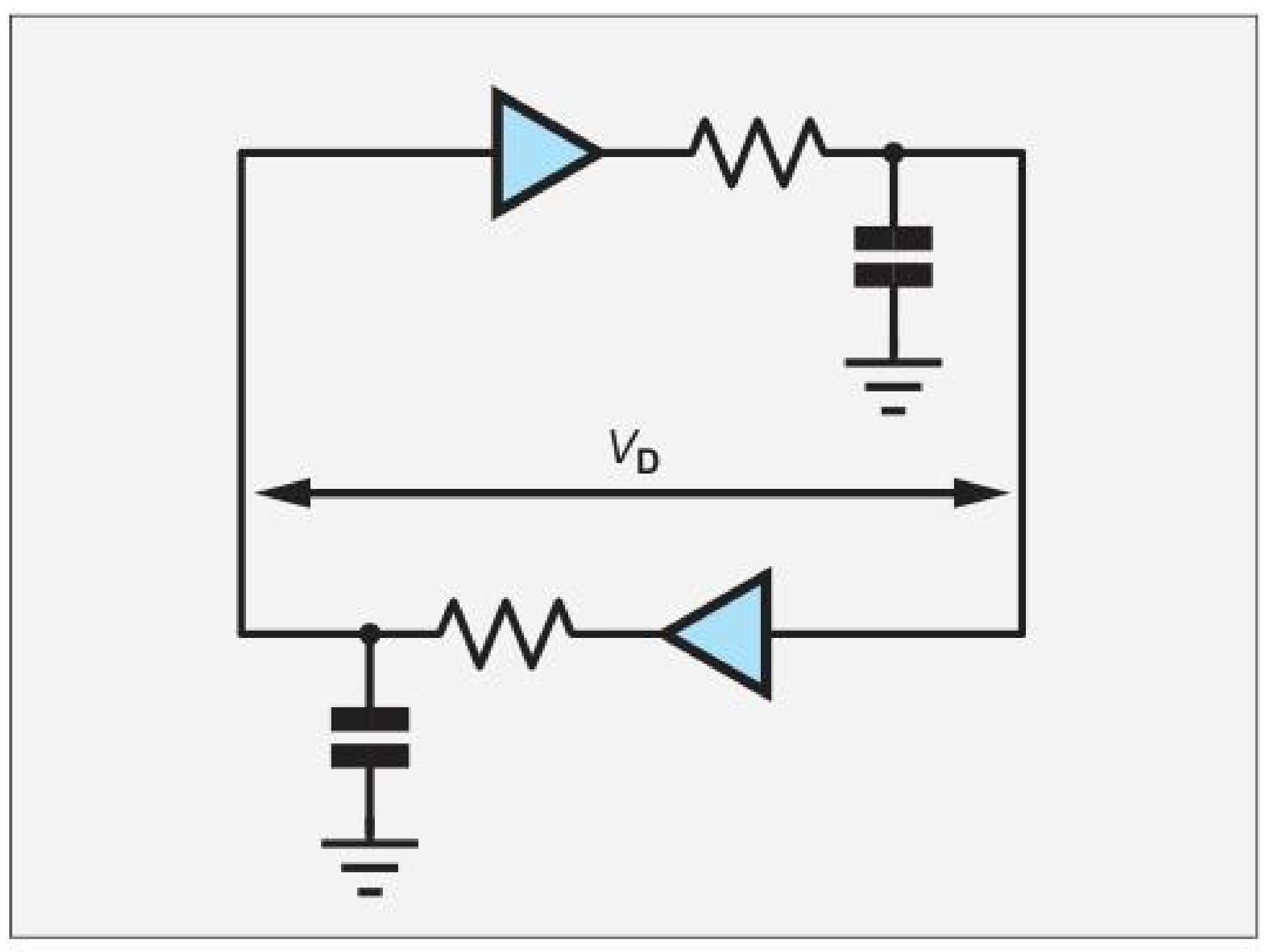


Fig.7. The inverter loop (see Fig.2) in the latch behaves like two amplifiers each driving an RC circuit.

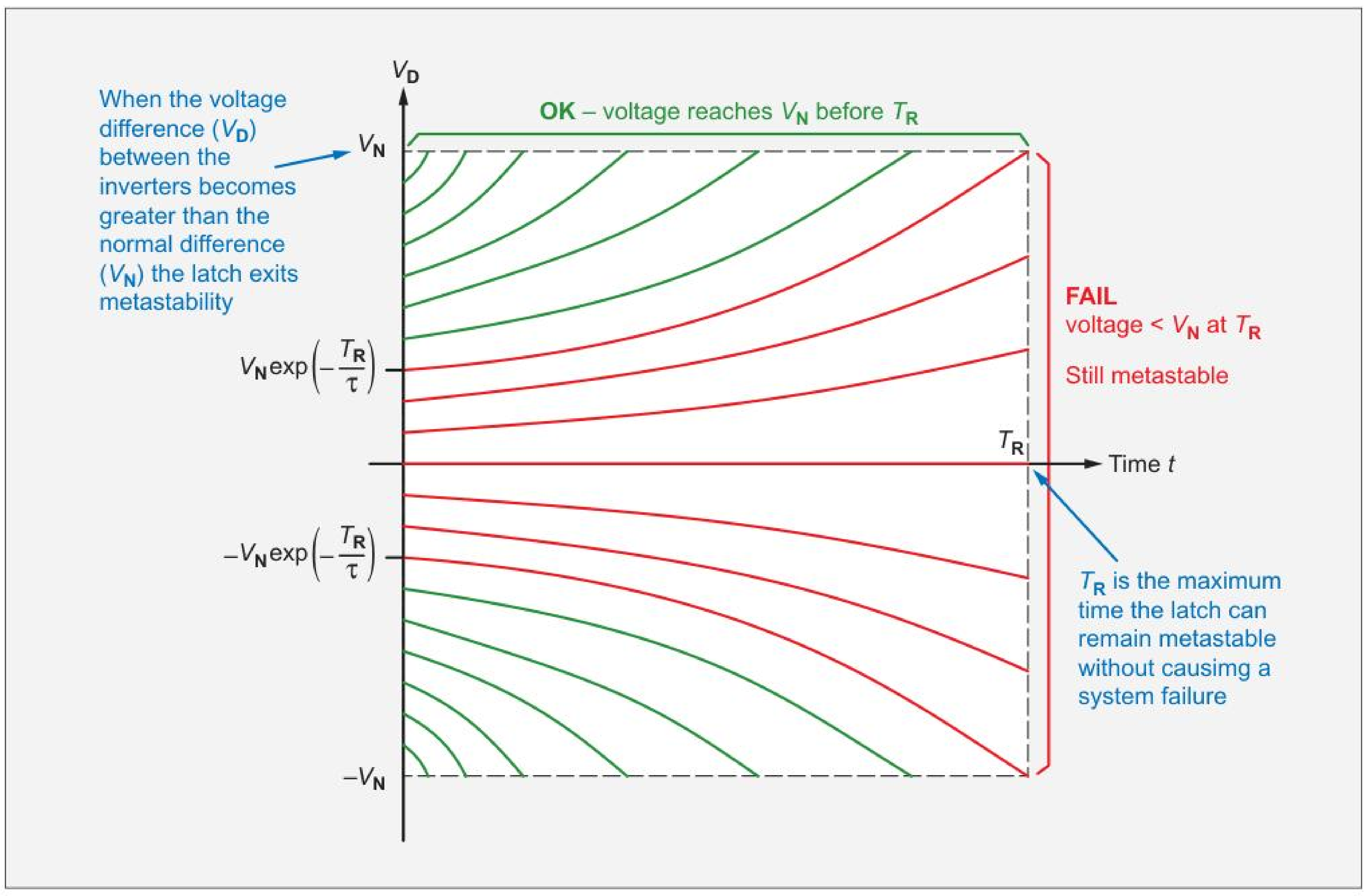


Fig.8. Voltage difference changes in a latch which enters metastability at time t = 0.

– call this V_N. From the solution of the loop differential equation, we can find the relationship between the initial voltage difference (V_{D0}) resolution time (T_R) and the metastability exit voltage (V_N). The boundary between the circuit failing and not failing occurs when the voltage difference just reaches V_N at T_R (see Fig.8). This occurs with a specific initial voltage difference V_{D0N}. From the circuit equation we find (if we solve the differential equation):

$$V_{D0N} = V_N \exp\left(-\frac{T_R}{\tau}\right)$$

Here, τ is the time constant of the latch loop – it depends on resistor and capacitor values and amplifier gain (Fig.7).

Probabilities and MTBF

If the clock happens to occur within the time range designated as T_0 in Fig.3 then the latch will go metastable. Within this period, we will assume that all initial voltages (V_{D0}) occur with equal probability. The probability that the latch fails (given that it went metastable in the first place) is the probability that the latch is still metastable after the acceptable T_R – call this P_S ('still metastable' probability). This is the probability that V_{D0} is less than V_{D0N}. Given the assumption that all V_{D0} values are equally probable, the failure probability is simply the proportion of metastable V_{D0} values less than V_{D0N}. The maximum value of V_{D0} for metastability is V_N as initial voltages above this implies normal operation. So, the probability of failure after entering metastability is $P_S = V_{D0N}/V_N$. From the exponential equation above we get:

$$P_S = \exp\left(-\frac{T_R}{\tau}\right)$$

This gives a probability that the latch will fail if it has become metastable, but for an overall failure probability (P_F) we also need to know the probability that the latch enters metastability in the first place (P_E). This is more straightforward to calculate and was mentioned in last month's article. The probability of a latch becoming metastable is basically the proportion of the clock cycle taken by T_0, that is $P_E = T_0/T_C$ – we assume the asynchronous signal can change at a point of the clock cycle with equal probability. We can also write this as $P_E = f_c T_0$, where f_c is the clock frequency. The probability of the latch failing (P_F) is the probability that it both enters metastability and that it is still metastable after the acceptable resolution time. If something is dependent on two conditions occurring together we multiply the probabilities to find the overall probability, so $P_F = P_E P_S$.

Digital circuits are processing information continuously, so a single failure probability is not very useful. We are more interested in how often the circuit will fail in operation. Given an asynchronous input to a synchronous latch, the rate of failure will be given by the rate at which data is changing (the data rate f_D) and the probability of failure (P_F from above), which occurs each time the data changes. We get:

$$\begin{aligned}\text{Failure rate} &= f_D P_F = f_D P_E P_S \\ &= f_D f_C T_0 \exp\left(-\frac{T_R}{\tau}\right)\end{aligned}$$

It is common to discuss system reliability in terms of Mean Time Between Failures (MTBF), which is simply the reciprocal of failure rate (1/ failure rate). The MTBF for a flipflop is:

$$\text{MTBF} = \frac{\exp\left(\frac{T_R}{\tau}\right)}{f_D f_C T_0}$$

Note the change in sign in the exponential from taking the reciprocal.

Synchronisers

A typical strategy for avoiding errors due to metastability caused by asynchronous inputs to synchronous systems is to add a flip-flop, clocked by the system clock, between the asynchronous signal and the system input (see Fig.9). This is known as a 'synchroniser'. The idea is that it is OK for the synchroniser flip-flop to become metastable as long as it recovers by the next clock cycle – exactly the scenario we calculated the MTFB for above. An important thing here is that adding the synchroniser does not eliminate the possibility of failure of the system, but it will be lower than if the signal was input directly. The MTBF equation above indicates the performance of the synchroniser, but we need to be able to interpret the results correctly. Typically, 63% of items will fail in the MTBF time, so it generally needs to be considerably longer than the acceptable error-free lifetime of the system. The issue is compounded in large digital circuits which contain a large number

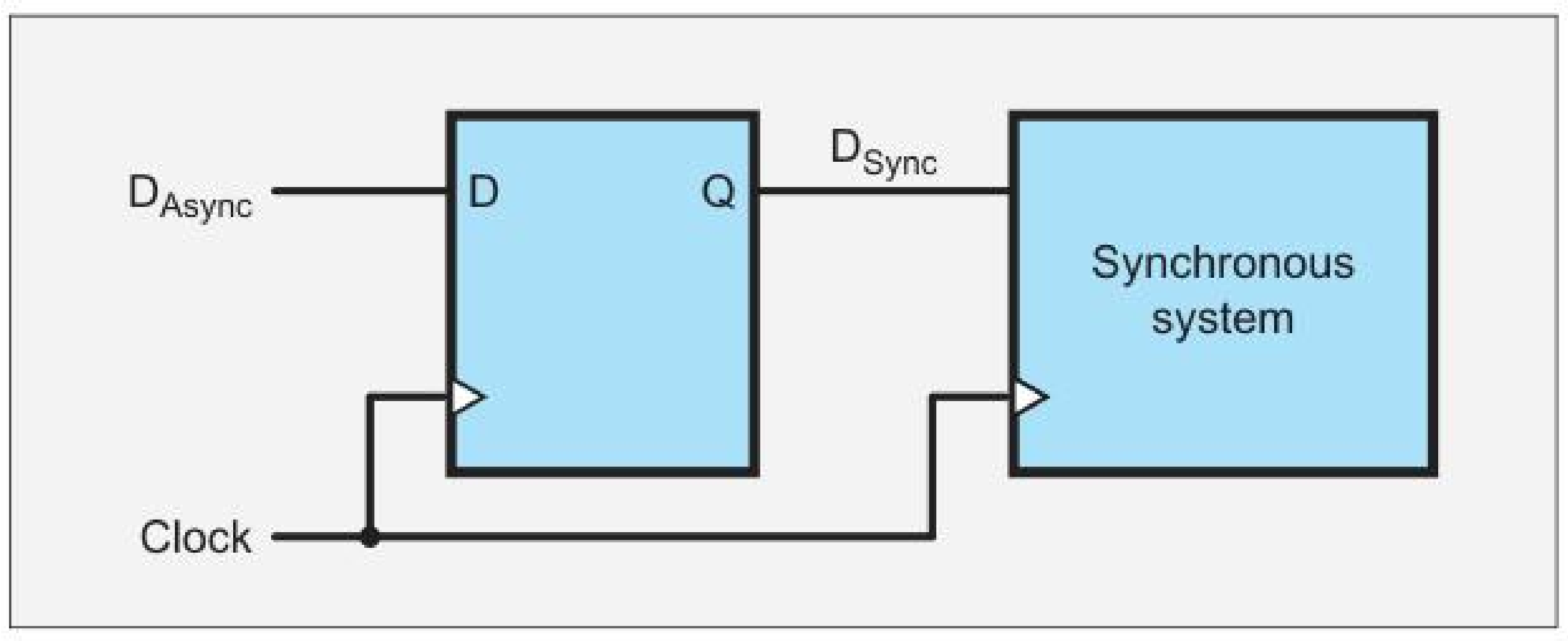


Fig.9. Single flip-flop synchroniser to protect a synchronous system from metastability due to an asynchronous input.

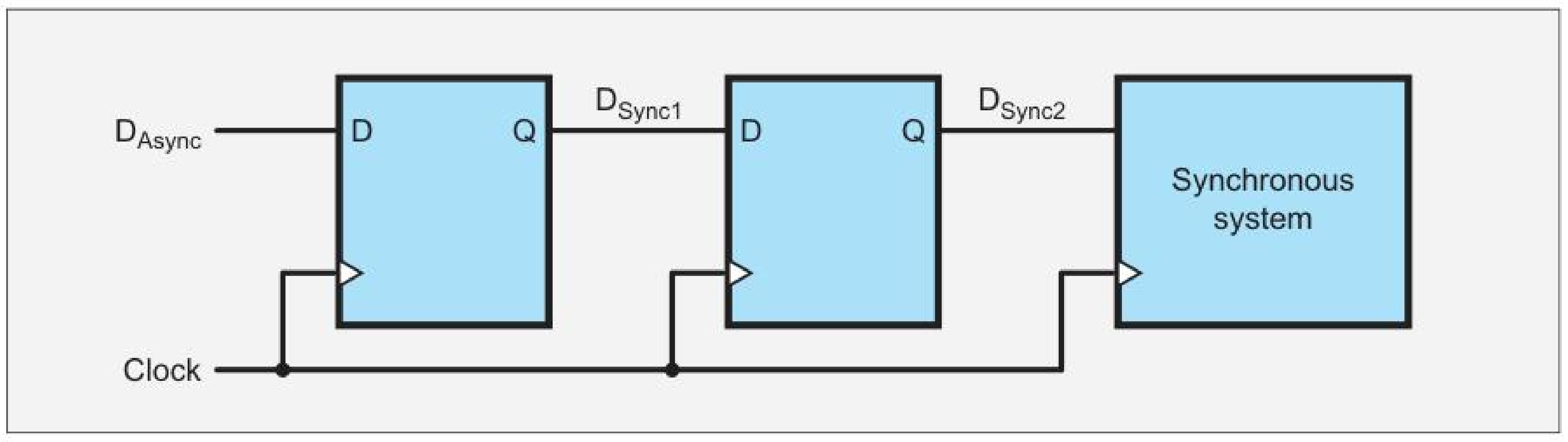


Fig.10. Two-flip-flop synchroniser.

of synchronisers – the system may fail if any one of them fails.

If we know the values for τ and T_0, which are dependent on the specific technology and flip-flops used, then we can calculate the MTBF. The clock and data rates should be known from the system specification and T_R is typically the clock period minus the setup time of the synchronous system input and any propagation delays from the synchroniser to the system.

Example

As an example MTBF calculation, we will use τ = 65ps and T_0 = 400ps – these are not for a particular technology, just for illustration. Consider a system with a clock of 500MHz and an input data rate of 150MHz. The clock cycle is 2ns, so T_R must be less than this, say 1.6ns (again, just for illustrative purposes). Putting these numbers into the MTBF equation we get about 3.5 hours – so if we built many copies of our circuit, 63% would fail in the first 3.5 hours of operation. This is unlikely to be acceptable!

A possible solution, if a single synchroniser flipflop is unable to achieve a sufficient MTBF, is to use two or three in chain. For two flip-flops (see Fig.10) the probability that the second is metastable at the point the data enters the system is $P_F = P_E P_{S1} P_{S2}$ – that is, the first flip-flop has to enter metastability and still be metastable after T_R, causing the second one to enter metastability and it still has to be metastable after a further T_R. If both have the same parameters, we end up with a new MTBF equation with $2T_R$ instead of T_R in the exponential. Running this calculation with the values from the previous example gives a MTBF of about 150 million years and a much smaller likelihood of failure during the circuit's operational lifetime. In practice, it may be difficult to find values for τ and T_0, but hopefully these examples illustrate the fact that it is not necessarily obvious how many synchroniser stages are required.

Multi-bit synchronisation

The synchronisers shown in Fig.9 and Fig.10 can only be used for single-bit data. If we have multi-bit data, then it may seem that we could simply use a synchroniser on each bit in parallel. Unfortunately, the nature of metastability and the effect of slight differences in input timing, clock skew and the variability of individual flip-flops make this a very risky approach. Consider a single bit entering a synchroniser flip-flop; say it changes from 0 to 1 but causes metastability which resolves in time, so does not cause a failure. It may resolve to 0 or 1, depending on exactly what got captured in the latch. On the next clock cycle the input bit will have definitely settled to 1, so the synchroniser flip-flop will load a 1 with no metastability. The 1 enters the system OK in this scenario, but there is uncertainty as to which clock cycle this occurs in. This is fine for a single bit – it is asynchronous, so it is not expected in a particular clock cycle. For multi-bit values, which happen to change close to the clock, individual bits in a set of parallel synchronisers could resolve on different clock cycles. This would present corrupt data to the system for a clock cycle – which could be catastrophic, depending on the implications of inputting wrong values.

For transferring multi-bit data between synchronous systems, we must use different approaches. One way is to use synchronised handshake signals. The sender sets up a new data value, and only after this is stable sends a single-bit 'I have data for you' handshake signal via a synchroniser to the receiving system. The receiver sends a single-bit acknowledge signal back, again via a synchroniser, when it has loaded the data. This is effective, but relatively slow. For faster data rates a special FIFO (first in first out) memory can be used. Any FIFO contains a bank of dual port memory (it is written to and read from via different ports rather than a single bus) and acts as a buffer where data production and consumption rates may vary (like buffering online videos). If both sides use the same clock things are straightforward, but if they are asynchronous the problem is not synchronising the memory data but synchronising the counters that keep track of where the data is being written and read in the memory. These have to be compared to check for FIFO full and empty conditions. As one counter is associated with each asynchronous system, they are multibit values which have to be synchronised in order to perform the comparisons. The clever trick here is to use a Gray code number system for the counters. In Gray code an increment of one causes just one bit to change, so parallel synchronisers like those in Fig.9 and Fig.10 can be used on each bit. Since only one bit changes at a time, there is no possibility of corrupting the count value by different synchronisers resolving in different clock cycles.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 27: Having fun with a Micromite Plus – Part 2

Last month, we prepared a piece of stripboard to form the basis of a fun Micromite Plus (MM+) project – driving an RGB LED matrix panel. Having made the appropriate track cuts, installed the relevant wire links and soldered all the connectors in place, we now need to check that the stripboard has been assembled correctly. So, this month we will begin by testing it, easily achieved by stepping one-by-one through each element of the project. As you will see, each step simply involves connecting the relevant item to the stripboard, configuring the MM+ as necessary, and then checking that the relevant element works as expected.

This methodical manner of testing and configuration ensures that we end up with a fully working project. Once this is successfully completed, we can then download the program code to the MM+ to bring the RGB panel to life with a clock, temperature display and our version of the classic Mastermind game.

Before we begin

In this article, the terms 'MM+' and 'E64' both refer to the Explore 64 module. Likewise, the use of the term 'computer' refers to your machine (eg, a PC, laptop, tablet or Raspberry Pi) on which you are running a terminal application, for example TeraTerm.

The E64 comes in a variety of different PCB versions. Thankfully, they all have identical pinouts (on the two long rows of header pins), and they all have a microSD socket, which means we can use any version of the E64 for this project.

All E64 modules supplied by **micromite.org** include a mini-USB socket onboard, and this provides connectivity to your computer via a single USB lead. In this scenario, the computer would be supplying the E64 with the required 5V. Fig.3 from last month's article summarises the pinouts of the E64. Note the three pins associated with power (lower-right corner in the diagram), the middle one is labelled '5V'. When the E64 is connected to a computer via a USB lead, this 5V pin is effectively an *output* pin that can power hardware. However, this project will require more current than a computer's USB port can supply, which is typically limited to 500mA (or more if using a USB-C port). The reason we require more current is that the RGB panel contains many LEDs (as discussed last month) and that's why we need to use an external PSU.

Micromite code

The code in this article is available for download from the *PE* website.

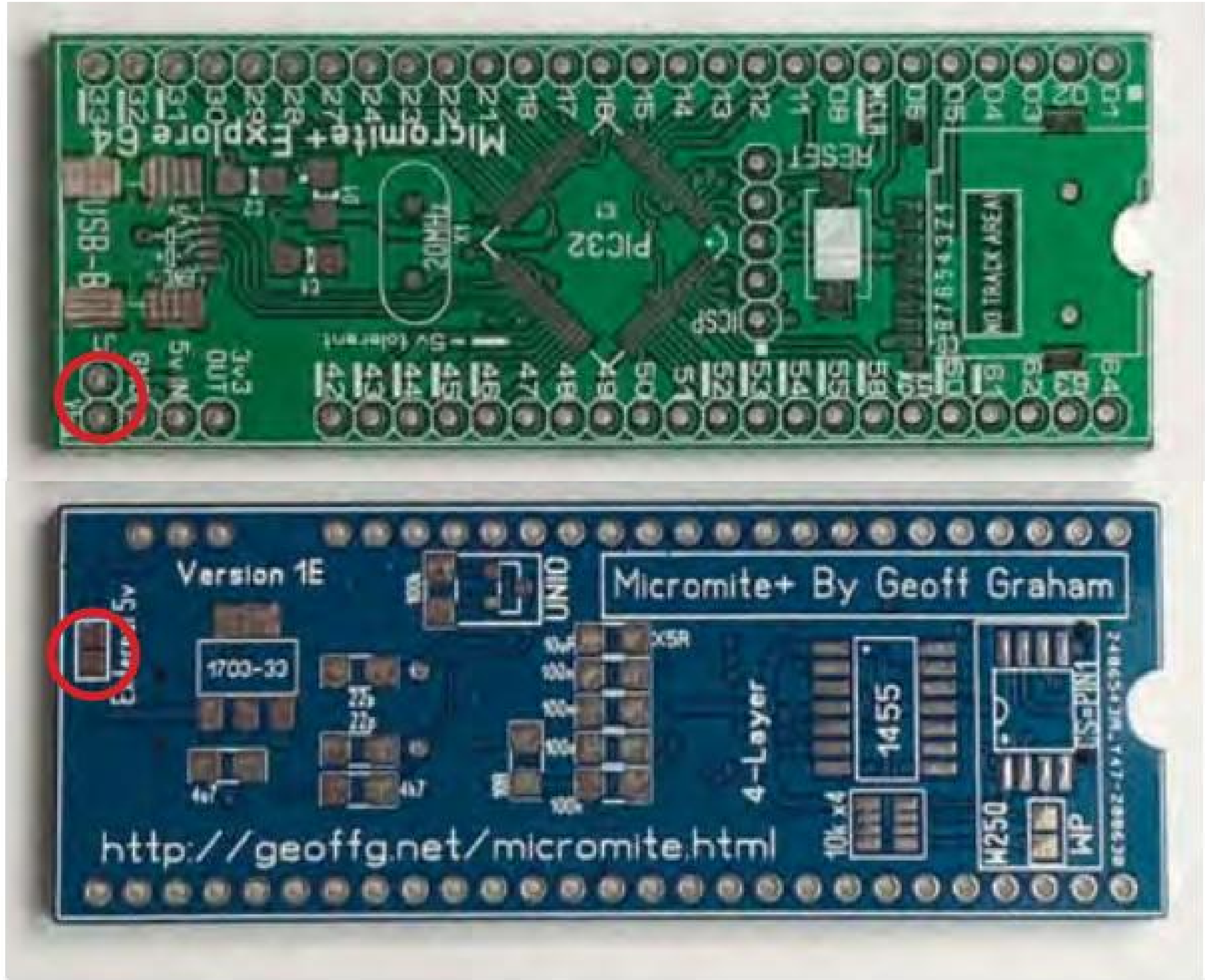

Fig.1. There have been six different versions of the the Explore 64 PCB, but they all have the same pinout (see Fig.3 from last month's article). However, there are only two USB power link positions: 1) (upper photo) PCB topside, a jumper link, or 2) (lower photo) PCB underside, a solder link. The positions of the links are circled in red.

So, by connecting the E64 via USB to a computer, we are able to configure the MM+ and also load the relevant software, but the E64's 5V output pin cannot drive more than a few RGB panel LEDs.

Important: power warning!

Returning to the E64's 5V pin mentioned above; with care, this can also act as a power *input* pin. So, along with the adjacent 0V pin, we can use these two pins to connect our external high-capacity 5V power supply. However, you *must* note the following. It is vital that you prevent any external 5V source from back-feeding to the E64's USB socket, which in turn would then supply 5V into any connected computer – this may cause irreparable damage to the computer.

On each E64, there is a USB power link, and for this project, it is very important to understand where it is located because we will need to add and remove it at various stages during testing. This link may be a traditional jumper link (topside), or a solder link (underside), as shown in Fig.1 above.

Understand that it is still possible for the computer to communicate via USB even with the link removed, since it is only the 5V 'wire' that is disconnected whenever the link is removed. Simply consider the link as only being required for initially configuring the E64 before the external 5V supply is connected.

In summary, you must remove the USB power link whenever the external 5V power supply AND the computer are both connected simultaneously.

Once this project is up and running, we recommend you keep the link permanently removed. Should you need to make any software changes, then you can safely reconnect your computer without any danger of feeding back 5V.

Test steps

The following steps may appear lengthy, but don't worry; although there is plenty to do, many steps are quick to perform and most concepts will be familiar to you.

Step 1: Connect to the E64

First, we need to connect the E64 module directly to a computer so that we can use the terminal application to communicate with the MM+. Note that the E64 should not be plugged into the stripboard at this time (we will do that at Step 4). Also, the USB power link, as discussed above, must be installed. Use a mini-USB lead to connect the E64 to a spare USB port on your computer, launch your usual terminal application (eg, TeraTerm) and then select the correct COM port that your computer's operating system assigns.

Ensure that you can see the usual MMBASIC Command Prompt. Depending on the version of E64 that you have, you may see a power LED illuminate confirming that the E64 is powered up.

At the command prompt, type `OPTION BAUDRATE 115200` and then reset the MM+ by pressing the reset button on the E64. If you do not have a reset button, then simply remove the USB lead temporarily, and then reconnect to your terminal application. You may need to set the baud rate in your terminal app to reflect the new speed of 115200.

Step 2 – Insert uSD card

You will require a microSD (uSD) card for this project; and our advice is to use a branded one with a capacity of between 8GB and 64GB (Class 10 is fine). Smaller (or larger) capacities may not work, but one that meets the above conditions will likely work straight out of the packet if purchased new. If you are planning on using a uSD card that has previously been used, then Fat16 or FAT32 formatting is required. In this scenario, we recommend you use your computer to reformat the uSD card to wipe it clean (back-up any data first!).

Gently inset the microSD card into the uSD socket on the E64. Be careful to insert it with the correct orientation; if it feels hard to insert, then chances are the uSD card is the wrong way round. On proper insertion, you will feel a 'clicking' action. Note that in order to remove the uSD card, you need to gently push on the uSD card, and it will once again 'click' to signify it is released. In other words, the uSD socket is a 'push-push' type, meaning push the uSD card to insert it, and push again to remove it.

For the E64 to be able to access the uSD card, you will need to set an OPTION. However, it is worth checking first as the relevant OPTION may already be set. At the command prompt, type `OPTION LIST` and if any OPTIONs have been set, they will be listed here. You are looking for `OPTION SDCARD 12,14`. If you don't see it listed then type it at the command prompt, press `Enter` and then reset the MM+. Now type `FILES` and on pressing `Enter`, it should respond with a list of directories and files on the uSD card (even though there probably won't be any). Remove the SD card, and retype `FILES` and check that it responds with a message indicating that it cannot find the uSD card. Reinsert the uSD for now.

If you make a mistake when setting the OPTION, for example, you accidentally typed an incorrect pin number, then simply type `OPTION SDCARD DISABLE` first, reset the MM+, then re-enter the correct parameters.

Step 3 – Install the RGB panel display driver

The concept for loading the display driver will be familiar to you if you have been following the *MIWM* series. We simply load a program (the driver) onto the E64 and then save it into the LIBRARY area of the MM+. With the *MKC*, we would have used `AUTOSAVE` (with copy/paste and `Ctrl-Z`), however, we now have access to a uSD card, which we can use instead.

If your computer can access an SD card, then proceed with the following, otherwise use the `AUTOSAVE` method to load onto the MM+ the **RGB_Panel_driver.txt** file (available, along with this month's other files, for download from the April 2021 page of the *PE* website).

Remove the uSD card from the E64 and insert it into your computer. You may need an SD adaptor that makes the uSD appear as a full-size SD card; these typically come with any newly purchased uSD card. Download the **RGB_Panel_driver.txt** file, and copy it onto the SD card. Next, safely eject the SD card from your computer, and reinsert the uSD card into the E64. Upon typing `FILES`, you should see the file listed. At the command prompt, type `LOAD "RGB_Panel_driver.txt"` and on pressing `Enter` it will load it into the MM+. This can be checked by typing `LIST` or `EDIT`, or pressing `F4` (which in effect is the same as typing `EDIT`).

Once you have the driver code installed (either by `AUTOSAVE` or `LOAD`) we need to move it into the library area of the MM+. At the command prompt, simply type `LIBRARY SAVE`. This effectively keeps the driver code safely in the MM+ without the risk of it being erased by any future changes we make in the Editor. Note that if you are using an E64 which has previously been used with a different display, then we advise you type `LIBRARY DELETE` first to remove any potential conflicts (remember, the Micromite can only have one display driver installed at any one time).

To check the (correct) driver is installed, type `LIBRARY LIST` at the command prompt and you should see a shortened listing appear. If not, repeat the above steps. This completes the installation of the display driver.

Step 4 – Plug in E64

Begin by removing the USB lead from the E64. Next, carefully align the E64 module over the project's stripboard (sockets JS2 and JS3) ensuring that the E64's USB socket is towards the outer edge of the stripboard – see Fig.2. After fully inserting the E64, perform a quick visual check to ensure that all pins are located correctly. If you notice anything wrong, carefully remove the E64, and realign as necessary.

Now reconnect the E64 to the computer with the USB lead, restart the terminal app and check you still have communication with the E64. If not, unplug the E64 from the stripboard, check app connectivity, and if you find you only lose connection when the E64 is inserted into the stripboard, then this implies there is an error on the stripboard somewhere. You will need to do a thorough check and correct any errors before proceeding. Once you have the E64 installed on the stripboard, and can communicate with it via your computer, you can move on to the next step.

Step 5 – Plug in RTC

With the E64 still connected to the computer, correctly install the RTC onto JP1 (refer to Fig.2 for orientation). Then, at the command prompt, type `OPTION RTC 43,44` and reset the MM+. Now we need to set the time inside the RTC. To do this type `RTC SETTIME` *`yy,mm,dd,hh,mm,ss`* at the command prompt, replacing the six parameters with the correct date and time information. On pressing `Enter`, the parameter values typed will be stored. So, to set the RTC to 01:22:30 pm on 5 March 2021 you would type: `RTC SETTIME 21,03,05,13,22,30` (remember to use 24-hour clock values for the hours). To test the RTC is working correctly, power down the MM+ for a short while, power back up, then type `PRINT TIME$` to check that the time is maintained. If it shows a time of just after midnight (for example something like: 00:00:08) then you will need to check the RTC and associated links/tracks on the stripboard as this implies the time is not being maintained (unless you are doing this test just after midnight!). Type `OPTION LIST` to check you used the correct pin numbers (43 and 44), if not, then type `OPTION RTC DISABLE`, reset the MM+, and then re-enter correctly. If this is correct but the time is not maintained, then check the RTC is inserted correctly. If it still fails to maintain the time then you have a track or wire link error (and do check for shorts too).

Once you see the correct time maintained, you can move to the next step.

Step 6 – Plug in IR receiver

Next, insert the IR receiver with the correct orientation into JS1 – the IR 'bump' on the main part of the body needs to be facing outwards (refer to Fig.2). Now, download the **IR_Test.txt** program and load it on to the MM+ with either the `AUTOSAVE` method (copy/paste) or the `LOAD` method (uSD card). Then `RUN` the program and check that you see numbers appear in the terminal screen whenever you press buttons on your preferred remote control transmitter. If you don't see any numbers, check the circuit around JS1, and also check that you have the IR receiver inserted the correct way round. If still no numbers appear, then try a different remote control.

Once you see a number appear on the screen whenever you press a button, you will need to make a note of the exact numbers that are associated with the seven buttons that we will use to control the main program. These are the KeyCode values, something we discussed back in *Part 5* of this series (June 2019).

We will need the following buttons for controlling the RGB panel: Up, Down, Left, Right, OK, Menu, and Play. Choose the buttons on your IR remote control that closely match these functions and make a written note of the KeyCode numbers that appear. Press each button multiple times to ensure the number displayed is consistent. We will use these KeyCodes in the next step when we modify the program code.

Step 7 – Prepare program files and remove E64

Before removing the E64 module from the stripboard, we will first load the main program onto the MM+ and configure it with the KeyCode values noted in Step 6. Download the file **RGB_Panel_MainProgramv1.txt** and load it into the MM+ using the SD card and `LOAD` method. At the same time, copy the three bitmap files (.bmp) to the SD card. Then use the Editor to modify the first few lines of code to reflect the KeyCode values noted above – the comments in the code will make this self-explanatory. Press F1 to save the KeyCode modifications, and then type `RUN` to check no errors appear on the screen. You should see four pairs of numbers appear on the screen and then nothing will appear to happen. If you see this, then all is good.

Now disconnect the E64 from your computer by totally removing the USB lead, and then carefully unplug the E64 module from the stripboard. This will allow us to connect (and test) the external PSU without risking the E64 module.

Important: once the E64 is unplugged from the stripboard, remove the USB power link.

Step 8 – Connect RGB panel

The RGB panel comes with a short ribbon cable and also a power cable – these are both required for connecting the RGB panel to the stripboard. Referring to Fig.1b from last month, first insert one end of the ribbon cable into the left-hand 2×8-way connector on the back of the RGB panel. Then insert the power cable's connector into the power socket on the rear of the panel (located in the photo just to the right of the central 'chassis bar'). Both connectors have a 'key' on them to ensure they are inserted with the correct orientation. Next, insert the other end of the ribbon cable into SK2 on the stripboard. If you have not used a shrouded socket for SK2 (and instead used 2×8 pin headers) ensure that you get the cable orientation correct (refer to Fig.2). Next, insert the black power leads into screw terminal SK1 (hole position B36), and the red power leads into SK1 (hole position B34). Perform a quick test to ensure that both ends of these two leads are fully inserted and screwed in tightly.

Step 9 – External power supply

It is now time to connect the external power supply into screw terminal SK3. If using the recommended Raspberry Pi 4 official power supply, cut off the USB-C connector as close as you can to the connector (ensuring you unplug the PSU first!) and then strip the ends of the two cables in preparation for inserting into SK3. Ensuring the prepared ends are not shorted, power it up and carefully use your test equipment to identify which is 0V, and which is 5V. Unplug the PSU again, and then screw the identified 0V lead into SK3 (hole position W36), and the 5V PSU lead into hole position W34. Once the two PSU leads are screwed in tight, perform a quick visual test to make sure there are no shorts, and then power on. You may see the RGB panel flash brightly, and some LEDs may illuminate (this is fine); however, it is now important to do a quick voltage reading across both screw terminals to check that a reading of 5V (or slightly higher) is observed. If it is significantly lower than 5V then power down immediately and thoroughly check everything. Once you observe 5V across both screw terminals then you are ready to reinstall the E64.

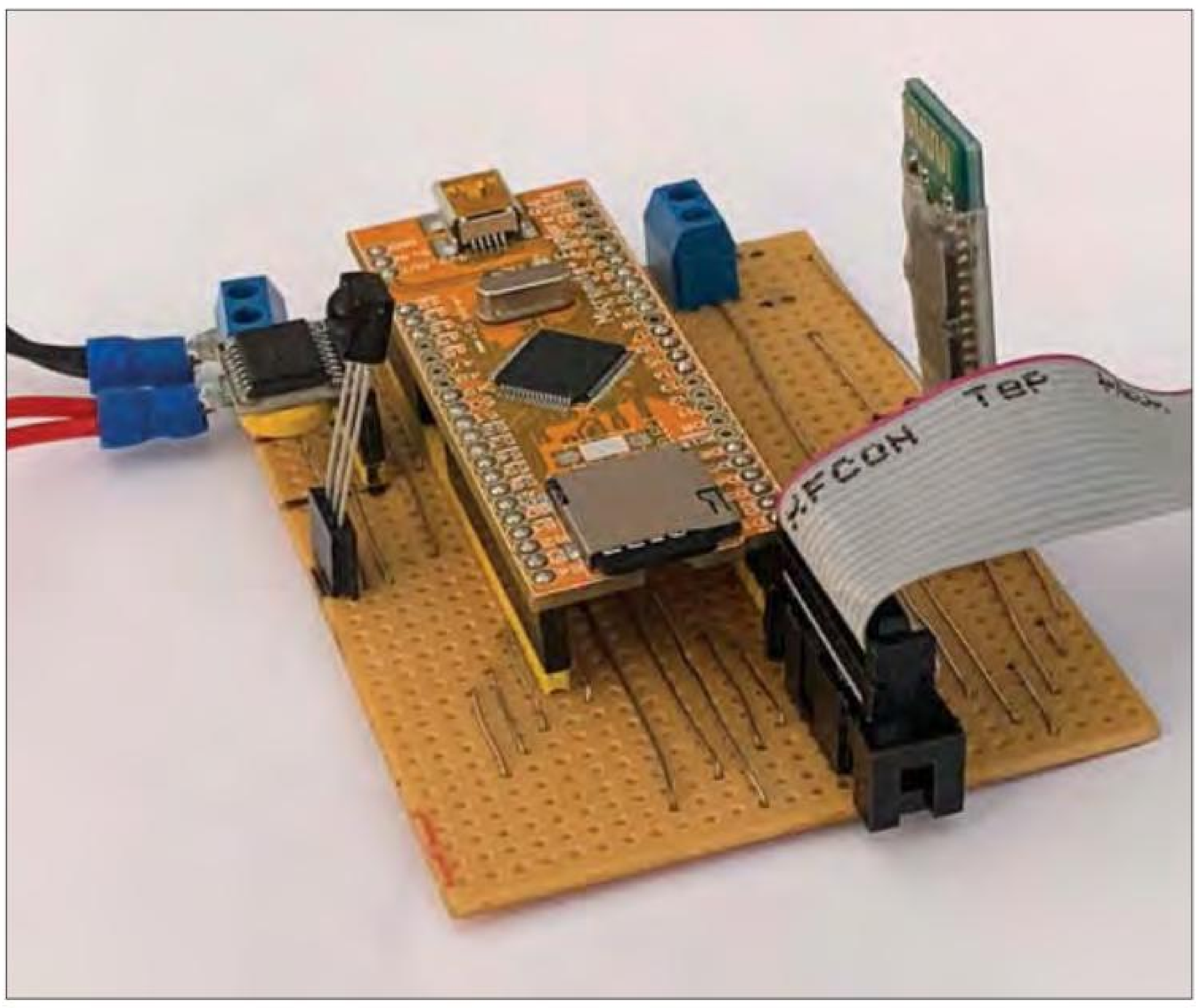
Fig.2. The Explore 64, RTC, IR receiver and optional Bluetooth module are shown here – note the correct orientation of each.

Step 10 – Plug in, switch on

We are nearly finished, but before proceeding, please ensure the following two points are observed, First, the USB power link on the E64 is removed; and second, the external PSU is unplugged (at the mains). When both of these conditions are met, carefully reinsert the E64 module with the correct orientation. Check all the pins are inserted correctly, and then plug in the external PSU. If all is good, you should see the time and date displayed on the RGB panel (similar to that shown in Fig.2 last month).

If the display remains blank, then connect your computer (USB power link *must* be off), and try to establish a connection with your terminal application. If you can establish a connection, and you are seeing the command prompt, then type `RUN` and you should see the RGB panel come to life. If you see nothing, try pressing `Ctrl-C` just in case the program is already running. Then at the command prompt, type `CLS RGB(RED)` and see if the panel turns red. If it doesn't, then you have a connection error somewhere and you will need to thoroughly check every wire link and track associated with the 2×8-way socket, SK2. Check also that the ribbon cable is positioned correctly at SK2, especially if you're only using 2×8-pin headers as opposed to a 2×8 shrouded header.

At this stage, you should now have the time and date on the display, with the flashing time 'colon' between the hours and minutes. If so, proceed to the next step, otherwise if you are stuck, then take two high-resolution photos of both sides of your stripboard, and email them to me with a brief description, and I will help you diagnose the issue.

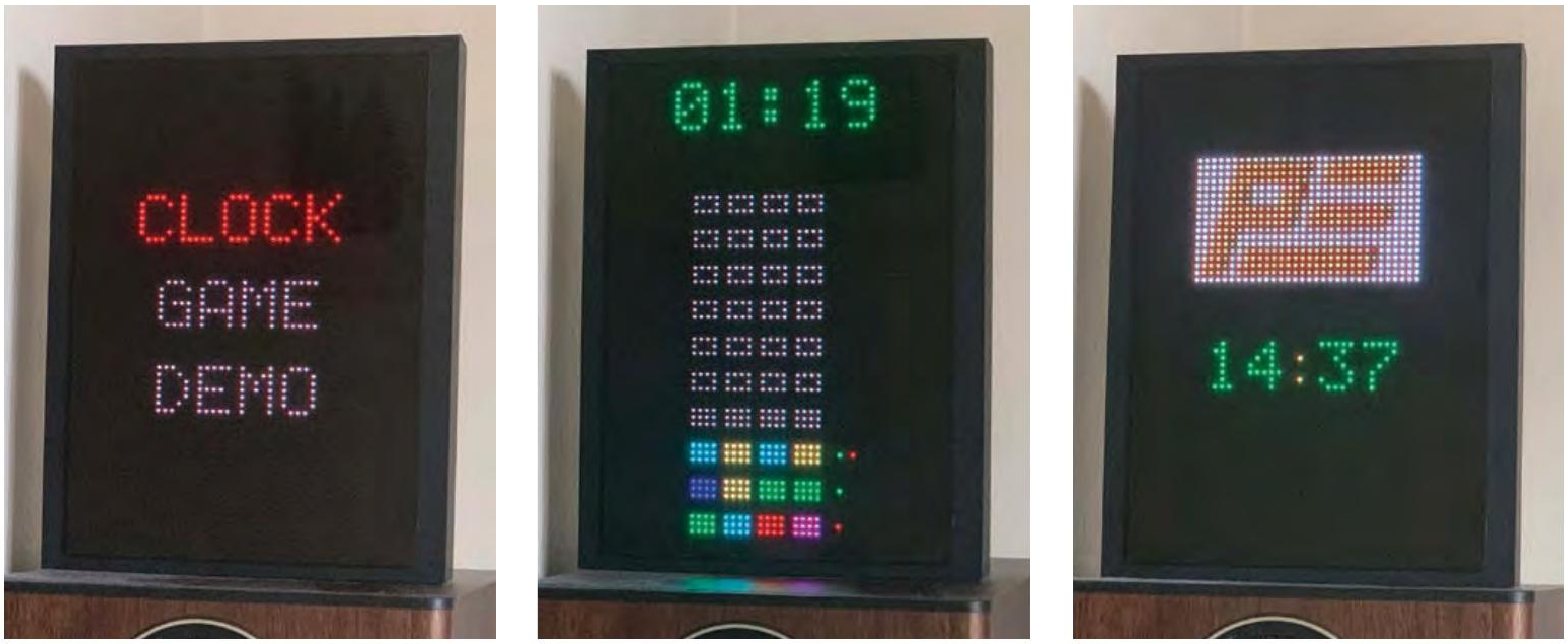

Fig.3. a) (left) The main menu screen that is displayed upon pressing the menu button; b) (middle) the Mastermind game in action; and c) (right) the 64×32 file (named **pic1.bmp**) stored on the uSD card is displayed when the 'Demo' function is chosen from the main menu.

Step 11 – Optional Bluetooth

Back in *Part 14* (March 2020) we discussed how to 'set your Micromite free' by using a pair of HC05 Bluetooth (BT) modules (or just one if your computer had built-in BT). If you have followed this series and implemented BT, then you can use the 'receiving module' and insert it directly into socket JS4. The component side of the HC05 should be facing the E64.

With the HC05 correctly inserted, connect your terminal application (set to 115200 baud rate) to the BT module and you can now access the RGB Panel remotely. This is very useful for making 'tweaks' to the project as you can leave it in situ, and don't have to insert a USB lead.

Finishing off

One thing you will notice is that the LEDs are very bright, so (ideally) we need a modification to make the RGB panel more pleasant (and easier) to read. This can easily be achieved by using a piece of LED-friendly acrylic positioned immediately in front of the RGB panel – the end result can look very professional. Ideally, the RGB panel needs to rest up against the acrylic for best affect. Examine Fig.2 from last month's article, you can see that we have used a piece of 'smoked'/tinted acrylic to 'diffuse' the LEDs. We used a black wooden photo frame, which also houses the electronics. The photo frame we used was just a low-cost one which had some depth to it (we removed the glass). We will not go into the precise details of assembly here as your mechanical and woodwork skills are no doubt superior to ours! We are just making this suggestion to finish of the project so that the display looks good.

Questions? Please email Phil at:
contactus@micromite.org

Using the software

We will not go into code details here, but we will briefly cover the features that are built into the program.

When first powered up, the program shows the date, time and temperature. Pressing the assigned 'Menu' button will take you to the menu (see Fig.3a). Use the Up and Down buttons to navigate to one of the three options and press OK or Play to select the highlighted function. In the Mastermind game (see Fig.3b), use the Left and Right buttons to navigate to the colour peg that you're guessing, the Up and Down buttons to change the colour of the peg, and the OK or Play buttons to enter your guess. The 'Demo' function will display any 64×32 bitmap file named **pic1.bmp** that is stored on the uSD card. We have made a bmp file available for download (see Fig.3c) – simply copy this onto the uSD card.

This project has shown you how to drive a 64×32 RGB LED panel, incorporate an RTC module and use an IR remote control for navigating functionality – here, a clock, a simple game, and displaying a bitmap image stored on the uSD card.

There is so much more that you could do with this hardware – remember, it is the software that makes the project behave in the manner it does. No doubt you could suggest several software improvements to what has been presented here, or even have your own ideas for a totally different project that is based on the same hardware. Maybe you could even mount it in an unusual enclosure that suits your specific requirements.

Competition

To encourage you to get involved, we invite you to build your own version of this two-part project and then enter it into our *RGB Panel* competition for a chance to win an amazing new *Colour Maximite 2* computer (the latest version – to be featured in *PE* very soon).

Your entry could be an exact copy of what has been presented here, or maybe a software improvement. Alternatively, you may want to include some additional hardware in order to expand on (or totally change) the overall functionality. All we ask is that your entry must at least use all the electronic hardware that has been used here.

As this may take you some time to complete, we have a closing date of 1 July 2021. Simply email us with a brief description of your entry, along with a few photos of your build.

A single prize of a *Colour Maximite 2* computer will be awarded to the best presented design. In addition, three £75 vouchers for use at **micromite.org** will be given to three lucky entries chosen at random.

Next month

This simple-yet-fun project has nicely demonstrated that by using a 64-pin Micromite Plus instead of the standard 28-pin Micromite it is possible to incorporate more powerful functionality and features into a project. However, don't forget that the 28-pin Micromite can still achieve some extremely impressive results.

Next month, we will return to the *MKC* and connect it to the popular and versatile ESP32 Wi-Fi module. By doing this, it becomes possible to extract data from the Internet; for example, accurate time information from an NTP server, or local weather information for displaying on a connected display. Until then, have lots of Micromite-based fun!

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Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

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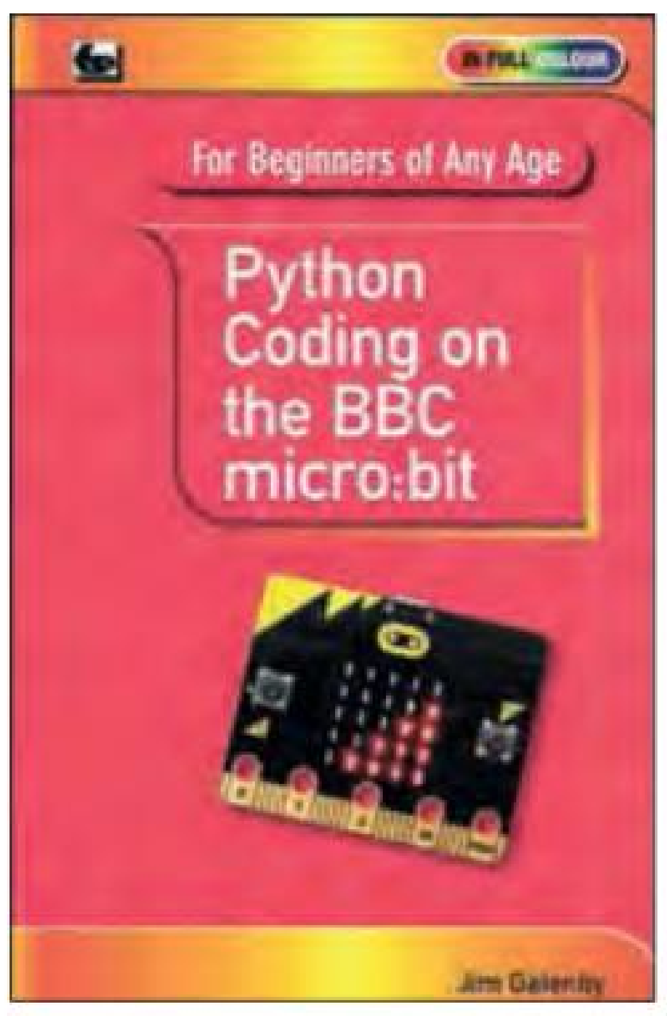

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Jim Gatenby

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GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

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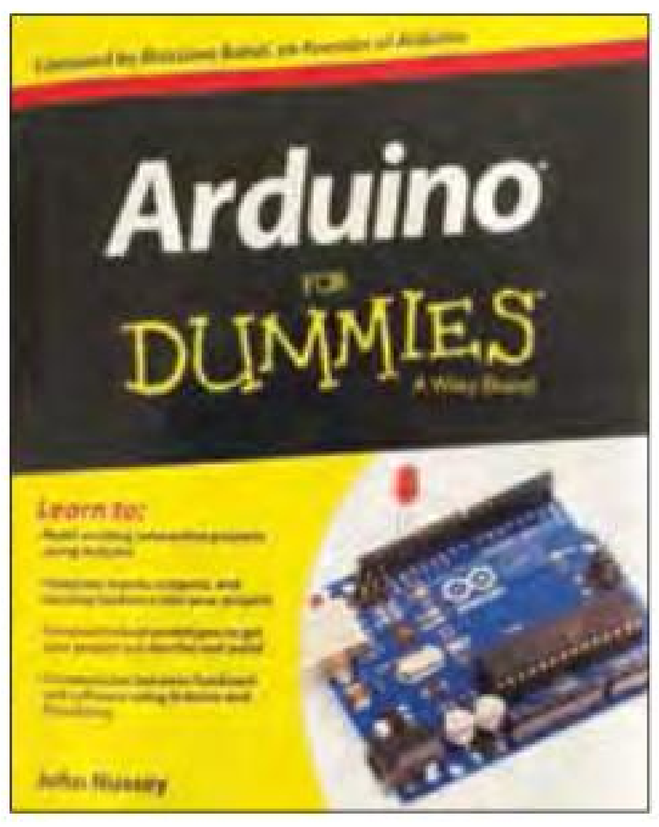

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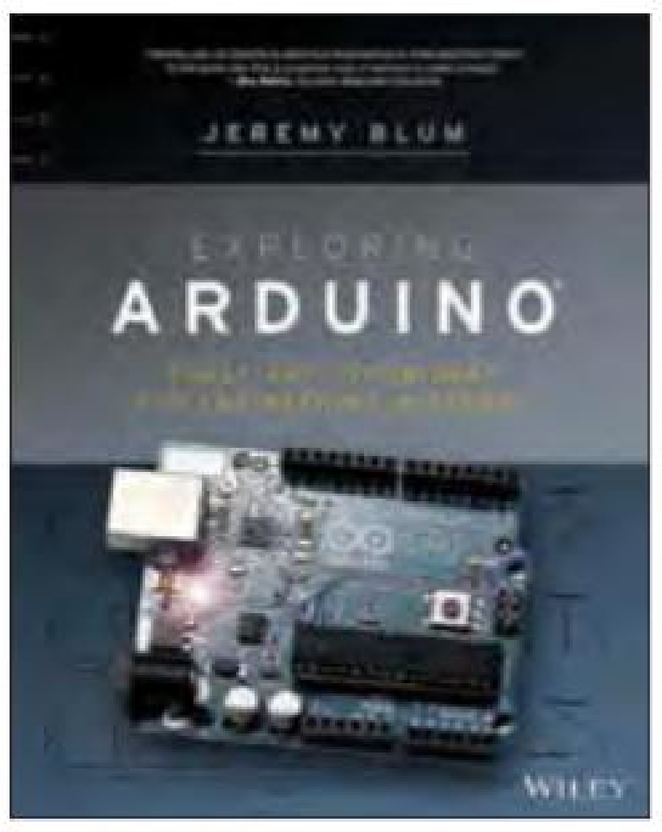

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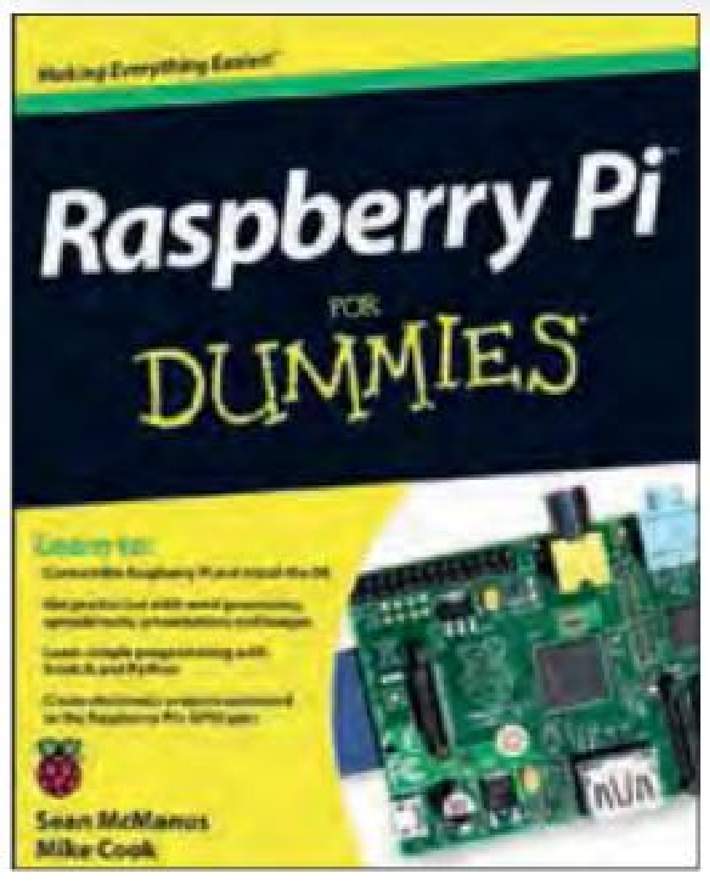

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Sean McManus and Mike Cook

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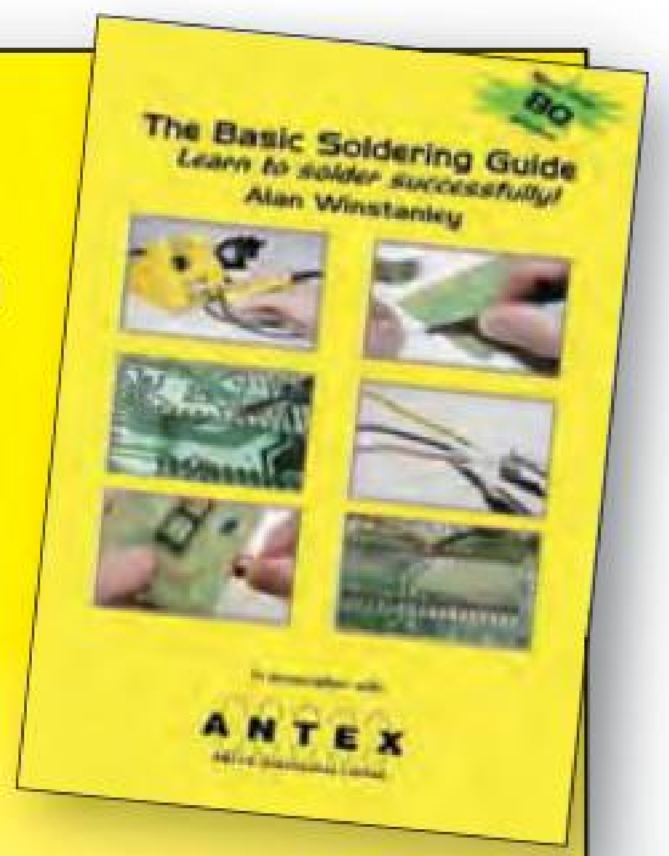

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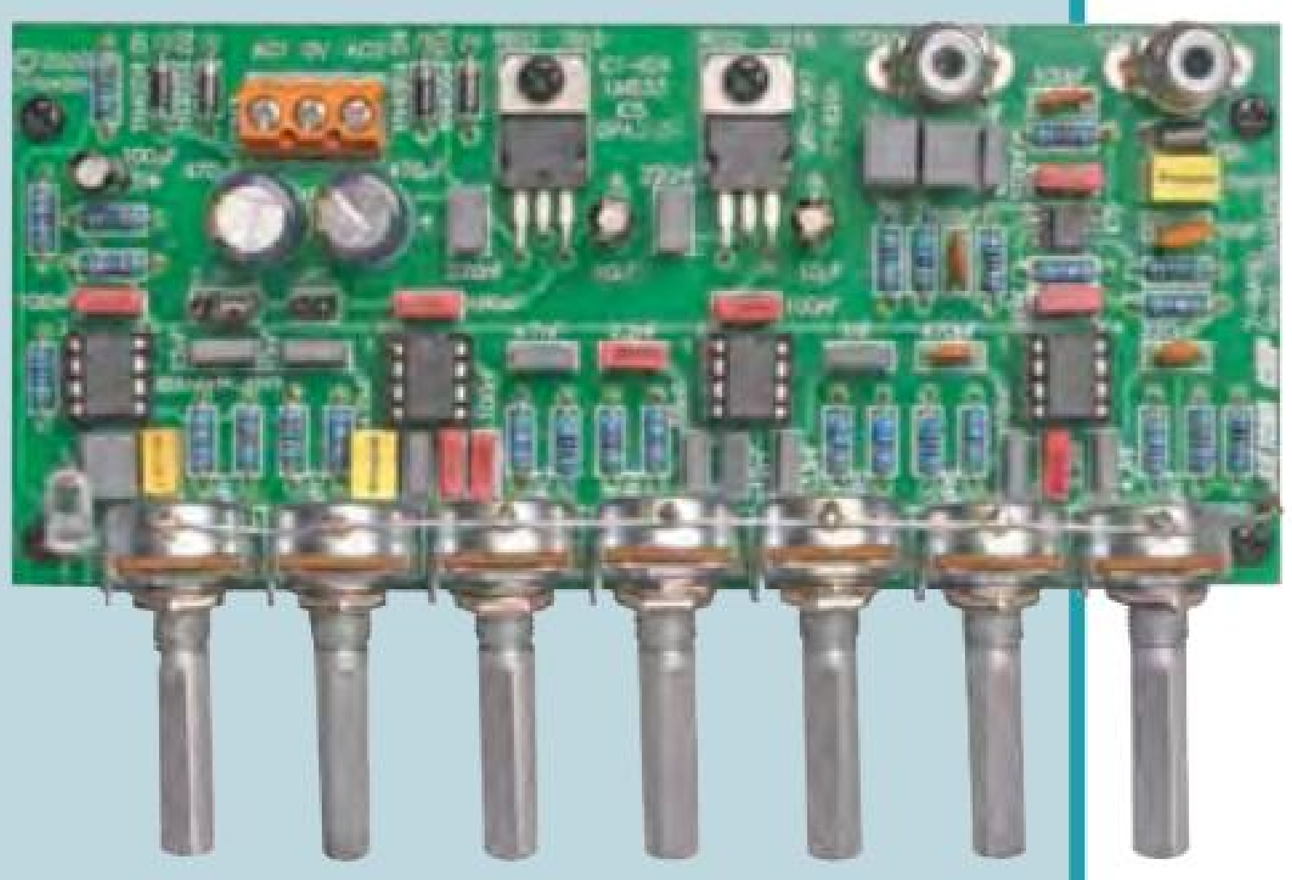
Next Month – in the May issue

DIY Solder Reflow Oven with PID Control – Part 2

When we left in Part 1, we'd finished assembling the PCBs and the hardware. Now all that's left is to put it all together – and get cooking!

Touchscreen Car Altimeter

This fun project is optimised for use in a car, truck or other land-based vehicle. The hardware has been designed to be powered from the vehicle, while the software has been specifically written to make its readings accurate on a typical driving trip.



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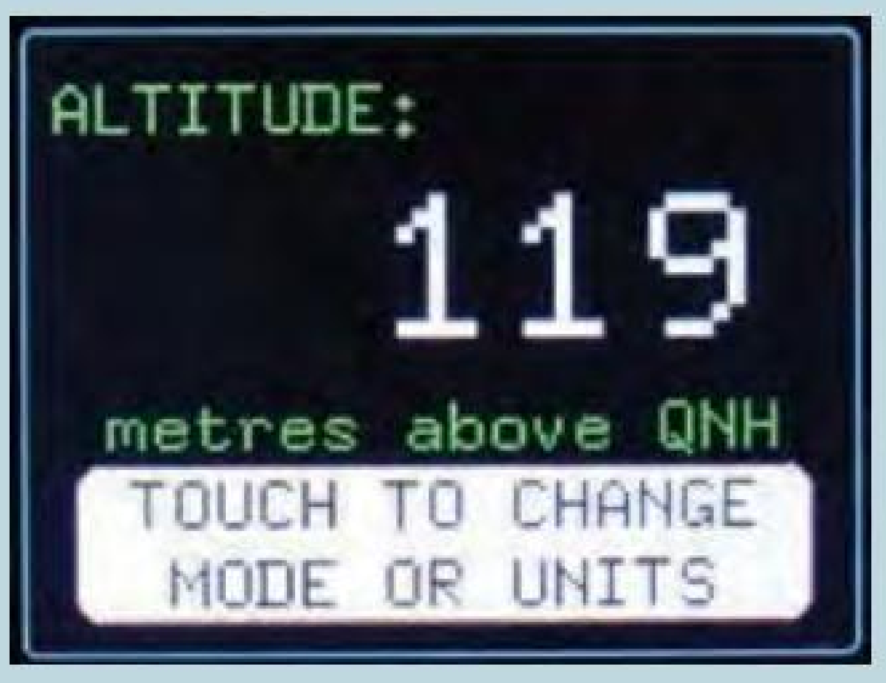
KickStart: Part 3

This third instalment shows you how to design and realise inductive components in a wide range of electronic applications and, in keeping with the *KickStart* series philosophy, we've provided sufficient information for you to be able to start making use of inductors in your own projects.

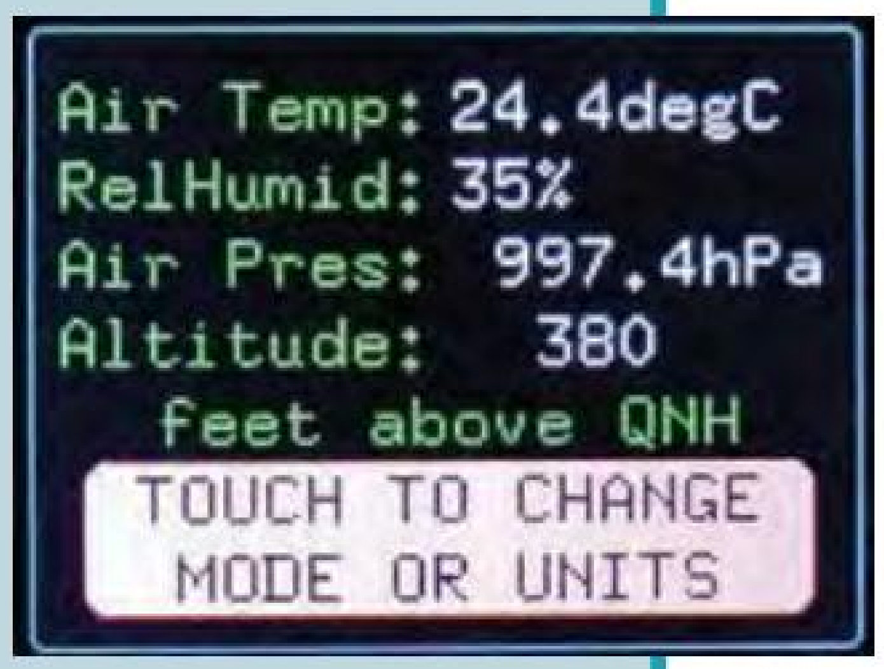


ALTITUDE:

119

metres above QNH

TOUCH TO CHANGE
MODE OR UNITS



Air Temp: 24.4degC
RelHumid: 35%
Air Pres: 997.4hPa
Altitude: 380
feet above QNH

TOUCH TO CHANGE
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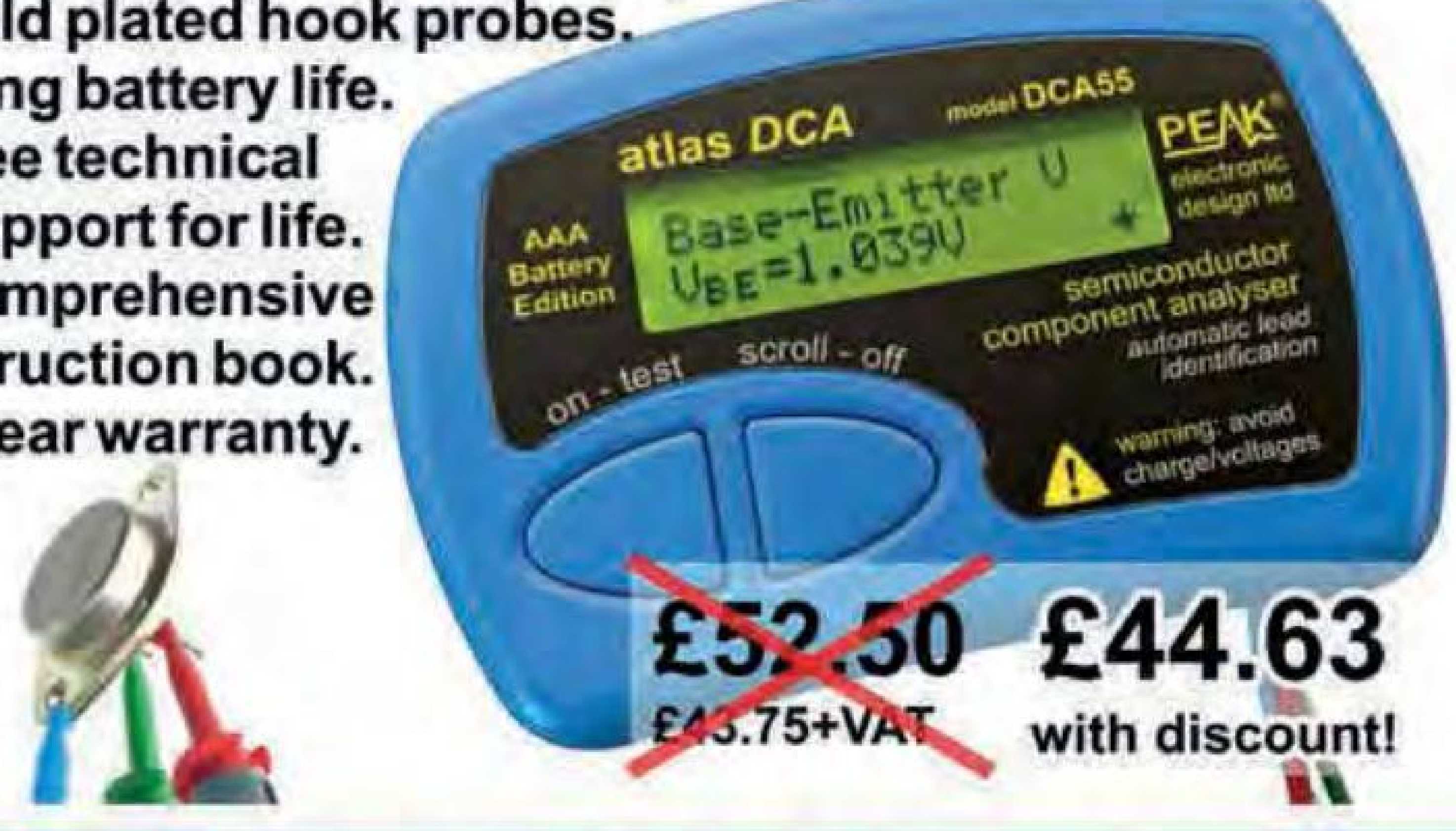
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